Development of the SID-IIs FRG

Heather Rhule
Vehicle Research & Test Center
NHTSA

Alena Hagedorn
Transportation Research Center, Inc.

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1. Executive Summary

As the NHTSA prepares to upgrade FMVSS 214, the only existing small female side impact dummy, SID-IIs, is being evaluated for possible incorporation into the standard in order to assess injury potential for smaller occupants. In component and sled testing at the Vehicle Research and Test Center (VRTC), the SID-IIs dummy exhibited several durability issues including damaged ribs, bent potentiometer shafts, and crushed potentiometer housings, making it difficult to assess biofidelity, repeatability and reproducibility of the dummy. If the dummy is not durable enough to withstand the laboratory testing designed to evaluate it, it is possible that damage may occur in the crash environment. In order for the SID-IIs dummy to be an adequate test tool for use in regulatory testing, the durability problems needed to be resolved. In addition to demonstrating satisfactory durability, the dummy must show reasonably good biofidelity, repeatability and reproducibility. Examination of the causes of the damage to the SID-IIs during evaluation testing revealed that the rib guides for the shoulder, thorax and abdomen ribs did not prevent vertical movement of the ribs and that the rib stops did not prevent excessive deflection of the ribs. Throughout the SID-IIs evaluation process, modifications to the shoulder, thorax and abdomen of the dummy were made by VRTC in cooperation with First Technology Safety Systems (FTSS) to address these problems.

The final design, referred to as the SID-IIs FRG, includes the following modifications: a Floating Rib Guide (FRG) system, a modified shoulder rib, a redesigned shoulder rib guide and more robust rib stops. As vertical movement of the ribs was responsible for the damage to the thorax and abdomen regions of the dummy, VRTC developed and fabricated the FRG system, which prevents the ribs from leaving the horizontal plane with guides that “float” with the ribs as they expand in the A-P direction. The final FRG design, enhanced by FTSS, includes carbon fiber cover plates in the front and rear of the dummy for both the thorax and abdomen regions, spring pins on four out of ten guides, guide pins on six out of ten guides, and rib guides $^{3}/_{8}$" deeper than those of the unmodified Original SID-IIs. During the VRTC evaluation of the SID-IIs, the Occupant Safety Research Partnership (OSRP) group made a minor change to the dummy to improve repeatability that included removing the inside pocket from the jacket and attaching the thorax and abdomen pads directly to the ribs using Velcro. VRTC testing and analysis showed that attachment of the pads with cable ties yielded better repeatability and were easier to use than Velcro. As a result, VRTC incorporated the cable tie attachment of the pads to the ribs. In addition, VRTC removed ¼" from the top of the abdomen pad to avoid interference with the thorax pad.

The shoulder of the Original SID-IIs dummy also experienced damage due to vertical motion of the shoulder rib. The shoulder rib guide was not sufficient to keep the shoulder rib in a horizontal plane and prevent damage. A simple re-shaping of the guide and an increase in its depth beyond the front of the shoulder rib was implemented by FTSS. Additionally, the damping material of the shoulder rib assembly was modified by FTSS such that a thinner piece of damping material was adhered along the full height of the rib steel to reduce the likelihood of the damping material being sheared off of the steel rib.

Finally, inadequate rib stops led to bent rib deflection potentiometer shafts and crushed potentiometer housings. The Original SID-IIs flexible urethane stops were replaced with vinyl-coated aluminum stops by FTSS. In order to further protect the instrumentation, the maximum deflection range was reduced from 69mm to 60mm, which would still allow deflections well above any reasonable injury criteria to be measured.

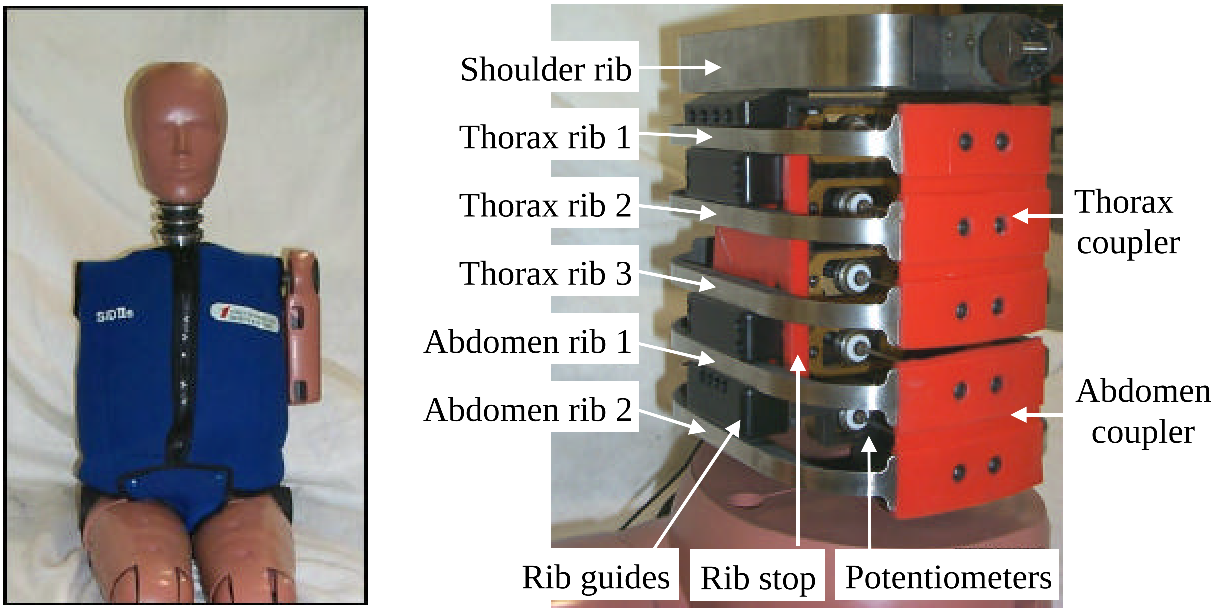
During the SID-IIs evaluation, a total of 232 tests, including quasi-static compression, dynamic compression, sled and out-of-position tests, were performed at VRTC with the Original SID-IIs and various versions of the redesigned FRG SID-IIs. All modifications of the final FRG design proved to be successful at preventing damage seen previously with the unmodified, Original SID-IIs dummy. In comparison tests with both the Original and final FRG dummies, the FRG displayed comparable measurements in all conditions except high-speed flat wall sled tests and high-speed lateral impacts. During these conditions, the FRG dummy exhibited smaller deflections (10% smaller with FRG), larger thorax load wall forces (17% larger with FRG) and larger T1 accelerations (20% larger with FRG). During high-speed impacts in which large deflections (greater than 45mm) were observed, the FRG response was stiffer than that of the Original dummy; however, its Biofidelity was not significantly altered. Since the dummy’s Biofidelity is relatively unchanged, the FRG design is superior, having improved durability. Further investigation is needed to determine the cause for the slight increase in stiffness, but it is suspected that as the springs of the FRG system compress with increasing rib deflection, the stiffness of the dummy increases.

The comparison tests also illustrated that when loaded at oblique angles forward and aft of the 90º lateral direction, small changes in impact angle result in large decreases in rib deflection measurements of both the Original and FRG dummies due to the potentiometers swinging about their attachment at the center of the dummy and the ribs contacting the rib stops. Maximum rib deflection measurements during oblique impacts were up to 50% less than those of pure lateral impacts.

In summary, the SID-IIs FRG successfully eliminates durability issues observed in the Original SID-IIs and introduces only a slight increase in stiffness at deflections greater than 45mm. As the Biofidelity of SID-IIs is relatively unchanged with the FRG, the FRG design is superior, having improved durability. Since significant reductions in deflection measurements were observed due to potentiometer swing in oblique impacts with both the Original and FRG dummies, it is apparent that the current design of the measurement apparatus does not measure deflections in the line of action of the impacting force during oblique impacts. In conclusion, the FRG SID-IIs offers an improved design over the Original SID-IIs for incorporation into the upgraded FMVSS 214 regulation.

2. Introduction

First Technology Safety Systems, a dummy manufacturer, and the Occupant Safety Research Partnership, a noncompetitive safety research consortium of Ford, General Motors and Daimler Chrysler vehicle manufacturers, jointly developed the SID-IIs Side Impact Dummy (Figure 1) in 1994 and 1995. The dummy was created to evaluate side impact protection systems such as side air bags. Its anthropometry is based on the Hybrid III 5th Percentile Female Dummy and closely matches the size and weight of a 12-13 year old child. As the NHTSA prepares to upgrade the Side Impact Protection Safety Standard (FMVSS 214), the small female side impact dummy is being evaluated for possible incorporation into the standard in order to assess injury potential for smaller occupants.



(a) (b)

Figure 1. Original SID-IIs Dummy seated with jacket on (a); shoulder, thorax and abdomen (b).

Since VRTC initiated the dummy's evaluation in the Fall of 2000, several durability problems have surfaced. The problems included bent potentiometer shafts, crushed potentiometer housings, sheared rib damping material, and deformed ribs. If the dummy is not durable enough to withstand the laboratory testing designed to evaluate it, it is possible that damage may occur in the crash environment. If damage to the dummy occurred in an FMVSS 214 test and the vehicle failed a test criterion, the damaged part of the dummy could be responsible for the test results rather than the performance of the vehicle's safety systems. In order for the SID-IIs dummy to be an adequate test tool for use in regulatory testing, the durability problems needed to be resolved. In addition to demonstrating improved durability, the dummy must show reasonably good biofidelity, repeatability and reproducibility.

Throughout the SID-IIs evaluation, modifications in the shoulder, thorax and abdomen of the dummy were made by VRTC and FTSS to address the durability problems. This report documents the history and evaluation of design changes made to the dummy between the Fall of 2000 and the Spring of 2003. The report is organized into four major sections: Floating Rib Guides (FRG), Shoulder Modifications, Rib Stop Modifications and FTSS Prototype FRG Evaluation. The Floating Rib Guides section discusses the damages that occurred in the thorax and abdomen regions of the dummy due to insufficient rib guides, and the development and evaluation of the VRTC prototype FRG system. The Shoulder Modifications section discusses the damages that occurred in the shoulder region due to an insufficient shoulder rib guide, and the development and evaluation of the FTSS-modified shoulder rib and rib guide. The Rib Stop Modification section discusses the damages that occurred due to insufficient rib stops and the development of new FTSS rib stops. The FTSS Prototype FRG Evaluation section discusses the differences between the FTSS Prototype FRG design and that of VRTC, the design changes made by VRTC to the FTSS prototype due to test results, and the evaluation of the final design. This section also documents dynamic component test comparisons between the Original SID-IIs dummy and the final design by FTSS and VRTC.

Figure 2 is a timeline showing the critical events during the design change phase including testing, results, and modifications. The timeline begins chronologically at the top of the Figure and ends at the bottom. The columns of the Figure are, from left to right, the years and months of the evaluation, the testing conducted, and three columns of test results (including modifications to the dummy). The Testing descriptions are color-coded to identify similar test types. Within the Test Results section of Figure 2, the modification types are organized into columns for FRG, Shoulder and Rib Stops. When the design was final in August 2002, the three columns for FRG, Shoulder and Rib Stops were merged into one column of Test Results (Final Design), as shown in Figure 2. Red and yellow events in the Test Results section indicate damage and design changes, respectively. The timeline ends in June 2003, when the evaluation of the modifications to the dummy was complete and the current design of the dummy, referred to as the FRG, was ready for a full evaluation.

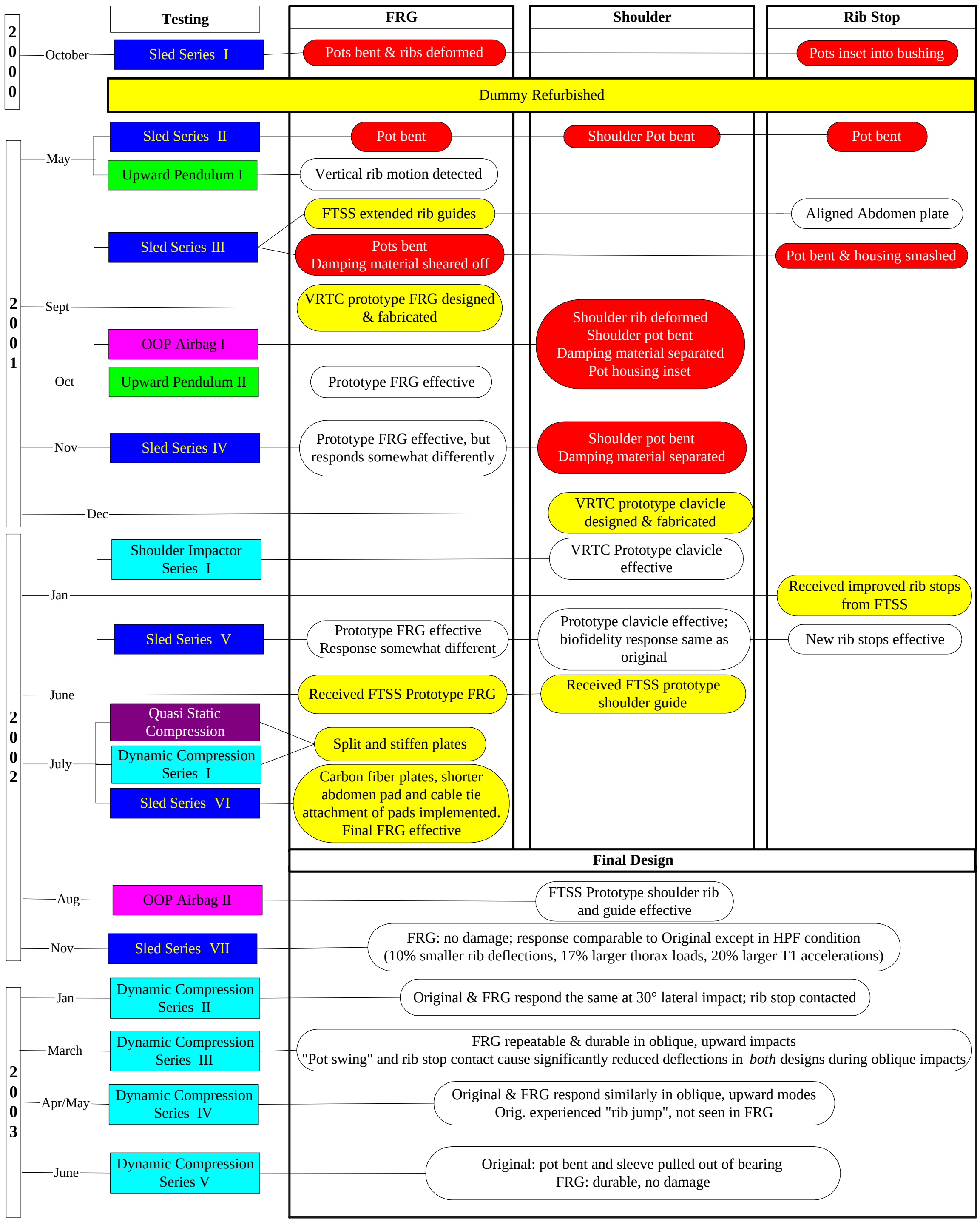


Figure 2. Timeline of Critical Events in the Evaluation of the Original SID-IIs

3. Background

A typical dummy evaluation includes exposing the dummy to environments relevant to its intended use. The SID-IIs dummy is intended to be used in side impact crash tests. Other side impact dummies such as the NHTSA-regulated Side Impact Dummy (SID), General Motors-designed Side Impact Dummy (BioSID), and European-designed Side Impact Dummy (EuroSID) have been evaluated using high- and low-speed rigid and padded flat wall sled tests (Donnelly, 1987; Zuby, 1991). Maltese, et al, (2002) reported response corridors for mid-sized male post-mortem human subjects for these test conditions as well as low-speed rigid and padded offset wall sled test conditions. The offset wall tests are used to examine the linkages among body regions of a dummy compared to those of human subjects. Table 1 lists the biofidelity test conditions and their abbreviations and Figure 3 shows schematics of some of the test conditions and a side view of the impact wall configuration.

Table 1. Sled Test Conditions Reported in Maltese, et al (2002).

Test Conditions	Abbreviations
8.9 m/s rigid flat wall	HRF
8.9 m/s padded flat wall (4 inches LC 200 103 kPa foam)	HPF
6.7 m/s rigid flat wall	LRF
6.7 m/s padded flat wall (4 inches LC 200 103 kPa foam)	LPF
6.7 m/s rigid thorax offset	LRT
6.7 m/s rigid abdomen offset	LRA
6.7 m/s rigid pelvis offset	LRP
6.7 m/s padded pelvis offset (4 inches LC 200 103 kPa foam)	LPP

In order to assess the biofidelity of the SID-IIs dummy with respect to the response corridors reported in Maltese et al (2002), the response corridors and test conditions had to be adjusted for a fifth percentile-sized female. A scale factor of the ratio of the sitting height of the SID-IIs to that of the standard SID was applied to the geometry of each plate of the impact wall, except for the leg plate. Then each load plate was positioned such that it coincided with the appropriate region of the dummy: T-Thorax, A-Abdomen, and P-Pelvis. Since the leg plate response was not critical in the evaluation of the SID-IIs, the leg plate used in the SID-IIs tests was of the same dimensions and location as that used in the Maltese human subject tests. Figure 3c shows the scaled impact wall configuration used for all Maltese sled tests with the SID-IIs. The distance of the offset plate from the impact wall was maintained at a depth of 4 inches, the same as was used in the Maltese tests. For the offset tests, the plate of interest (1/2-inch thick) was located 4 inches out from the wall using a 1-1/2 -inch diameter cylinder.

The 50th percentile male response corridors were scaled for the small female using an equal mass approach (Eppinger et al, 1984). All force, acceleration and deflection signals were scaled using the following equations:

$$\text{Velocity}: \quad V_s = V_i$$

$$\text{Acceleration}: \quad A_s = \lambda_m^{-1/3} A_i$$

$$\text{Deflection}: \quad D_s = \lambda_m^{1/3} D_i$$

$$\text{Time}: \quad T_s = \lambda_m^{1/3} T_i$$

$$\text{Force}: \quad F_s = \lambda_m^{2/3} F_i$$

where s is the subscript for scaled data, i is the subscript for 50th percentile normalized data and λ_m = 46.72/75 = 0.623 where λ_m is the mass scale factor, 46.72 is the average 5th percentile female mass in kilograms (Mertz et al, 1989) and 75 is the average 50th percentile male mass in kilograms (Maltese et al, 2002).

Analysis of the Maltese biofidelity test conditions showed that all of the biofidelity test conditions used in the NHTSA Biofidelity Ranking System (Table 1, except for LPP, LRT), with the exception of the High-Speed Rigid Flat Wall, were representative of Federal Motor Vehicle Safety Standard (FMVSS) 201, FMVSS 214, and Side

Impact New Car Assessment Program (SNCAP) crash conditions (Rhule et al, 2002). The OSRP group reported that a high-speed (8.9 m/s) flat, rigid wall sled test was too severe for the SID-IIs dummy (Scherer et al, 1998).

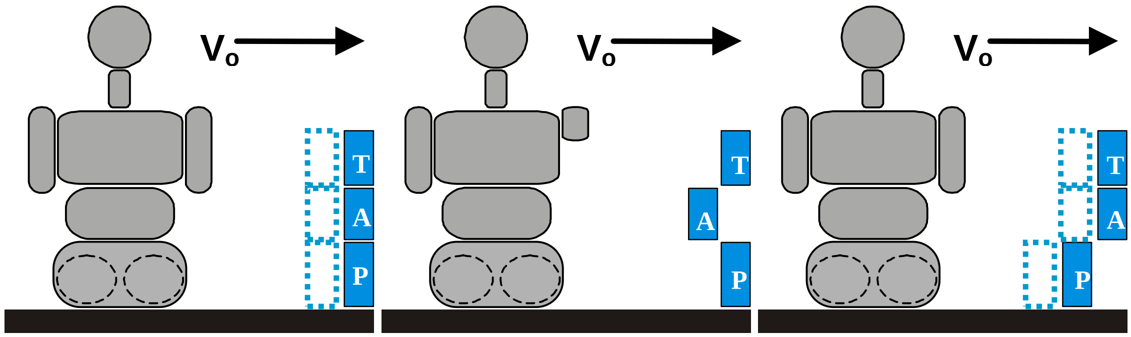


Figure 3a. Test condition schematics, from left to right: padded or rigid flat wall; rigid abdomen offset; padded or rigid pelvis offset

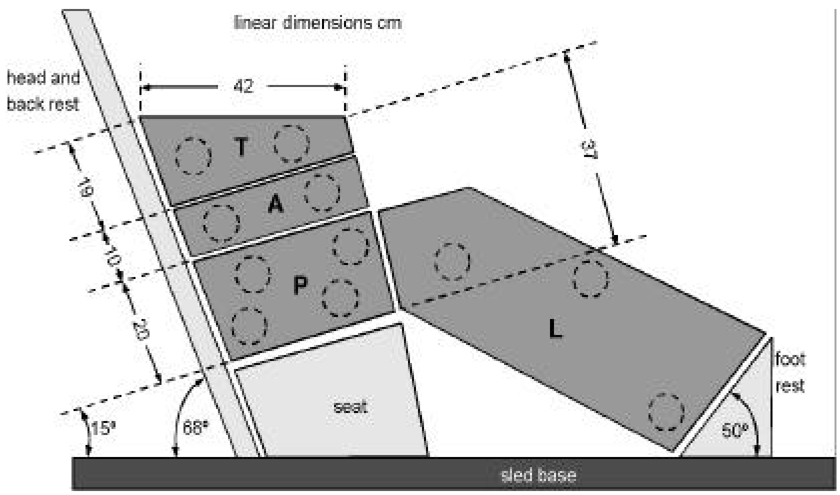


Figure 3b. Impact wall configuration for mid-size male showing thorax (T), abdomen (A), pelvis (P) and leg (L) plates.

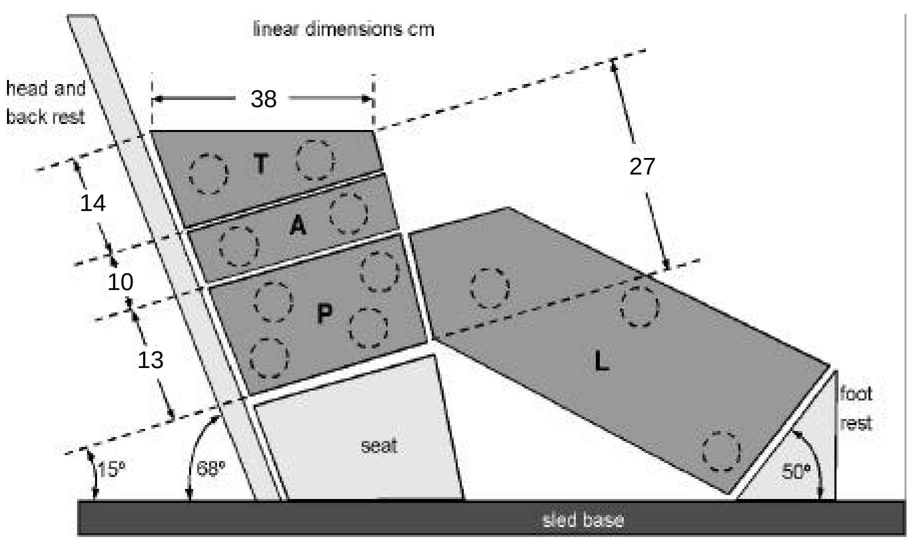


Figure 3c. Impact wall configuration used for SID-IIs dummy showing thorax (T), abdomen (A), pelvis (P) and leg (L) plates.

4. Floating Rib Guides (FRG)

Durability problems with the SID-IIs dummy began with the first sled test series and continued throughout the evaluation of the dummy. This section of the report documents, chronologically from October 2000 until June 2002, the damages that occurred in the thorax and abdomen regions of the dummy, the reasons the damage occurred, and the modifications to the design that resulted in the VRTC Prototype FRG. This prototype design was then improved upon by FTSS. In Figure 2, "Timeline of Critical Events in the Evaluation of the Original SID-IIs," the column labeled FRG correlates to this section of the report.

4.1 Sled Series I

In order to examine the SID-IIs dummy's biofidelity and performance in dynamic impact environments, the first sled test series that duplicated the test procedures of Maltese (2002) was conducted in October 2000 (see Table 2). In order to identify the dummy design used throughout the evaluation, a letter has been assigned to each design configuration used and is described in each of the tables showing the test matrices. For example, in Table 2, Dummy Design configuration A refers to the original design of the SID-IIs, with the jacket on. For each test, the dummy was positioned some distance from the impact wall in order to achieve dummy-to-wall contact during constant velocity of the Hyge sled. The dummy was positioned with its arm down for all tests except for abdomen and thorax offsets, where the arm was positioned at either 90 or 180 degrees relative to the ground and secured to assure that the arm would not interfere with the contact between the offset and the dummy. These procedures were followed for each sled series.

A shoulder plate was added to the sled wall in the first test in order to engage the shoulder. As an alternate test condition for evaluating the SID-IIs at 8.9 m/s, an air bag was installed in a flat wall in order to provide some cushion and enable the dummy's interaction with an air bag to be studied. In order to position the air bags relative to the dummy realistically, the dummy was positioned in the vehicles and measurements were taken for duplication on the sled. In Test 258, a 1999 Cadillac Deville passenger side airbag was used. In Test 259, a Nissan Maxima side airbag was used. Figure 4 shows the test setups with the air bag modules circled in green (4a, 4c) and the deployed air bags (4b, 4d) for Tests 258 and 259.

Table 2. Sled Test Series I Matrix

Test Conditions	Test Numbers	Dummy Design / Serial Number
6.7 m/s rigid flat wall (w/shoulder plate)	236	A / 020
6.7 m/s padded flat wall (3" 103 kPa foam)	237	
6.7 m/s rigid flat wall	238, 239, 240	
6.7 m/s padded pelvis offset (3" 103 kPa foam)	241	
6.7 m/s rigid pelvis offset	242	
6.7 m/s rigid abdomen offset	243	
6.7 m/s rigid thorax offset	244	
8.9 m/s flat wall w/air bag	258, 259	
<u>Dummy Design A</u>: original dummy with jacket on		

In the Rigid Abdomen Offset test of Sled Series I (Test 243), the upper abdominal potentiometer shaft was bent vertically, all ribs were slightly deformed and the damping material of abdomen ribs 1 and 2 was gouged (Figure 5a,b). The rib deflection data traces from Test 243 are shown in Figure 5c. During the high-speed airbag tests (Tests 258,259), the airbag deployed very late and the resulting impact surface was quite rigid. Potentiometer (pot) shafts bent and pot housings detached from their bushings (Figure 6). Damages from these two tests were assumed to be due to the severity of the test and not due to the dummy's design. In light of the damage resulting from these tests, the dummy was sent back to the manufacturer to be refurbished. A stronger adhesive was applied to strengthen the bond between the pot housings and their bushings during the refurbishment of the dummy.

4.2 Sled Series II

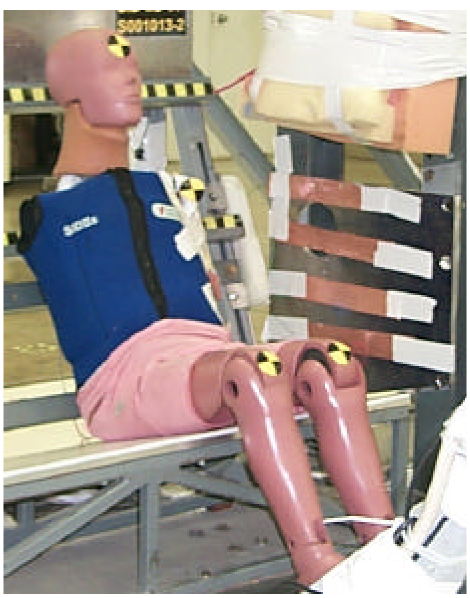
The refurbished dummy was delivered to VRTC in April 2001. In response to concerns from OSRP that the rigid offset wall tests were too severe for the SID-IIs dummy, a second set of sled tests was conducted in May 2001 with padding on the offsets. Low- and high-speed flat wall tests were conducted as before, except with four inches of 103kPa or three inches of 400kPa foam padding along the length of the impact plates. The severity of the tests was gradually increased, by increasing velocity then pad stiffness, to observe the effects on the dummy's response. The stiffer 400kPa padding was selected for use in the offset test configurations. Table 3 shows the matrix for Sled Test Series II. Dummy Design AR refers to the original SID-IIs design with stronger adhesive between the pot housings and their bushings, and the dummy jacket on. All damaged parts on serial number 020 were replaced prior to Sled Test Series II.

Table 3. Sled Test Series II Matrix

Test Conditions	Test Numbers	Dummy Design / Serial Number
6.7 m/s padded flat wall (4" 103kPa foam)	516	AR / 020
8.9 m/s padded flat wall (4" 103kPa foam)	517	
6.7 m/s padded flat wall (3" 400kPa foam)	518	
8.9 m/s padded flat wall (3" 400kPa foam)	519	
6.7 m/s padded thorax offset (3" 400kPa)	520	
6.7 m/s padded abdomen offset (3" 400kPa)	521	
6.7 m/s padded pelvis offset (3" 400kPa)	522	
Dummy Design AR: original dummy, refurbished, with stronger adhesive between pot housings and their bushings; with jacket on		

(a)

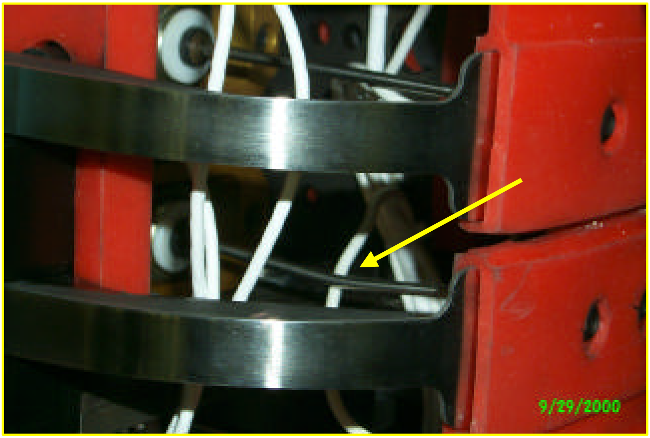
(b)



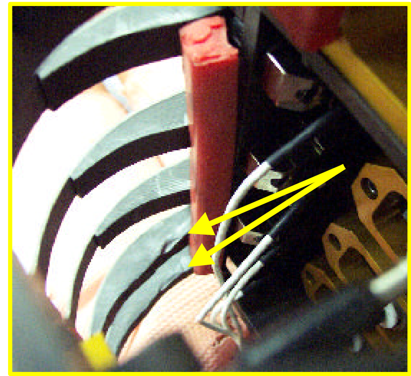
(c)

(d)

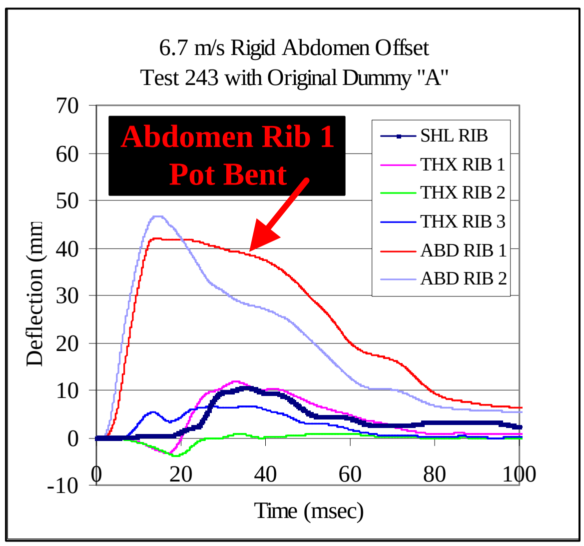
Figure 4. High-speed Flat Wall Airbag Tests: Test 258 setup with Cadillac door-mounted passenger side airbag (a); Post-test photo after Test 258 showing deployed airbag (b); Test 259 setup with Maxima seat-mounted side airbag (c); Post-test photo after Test 259 showing deployed airbag (d).



(a)

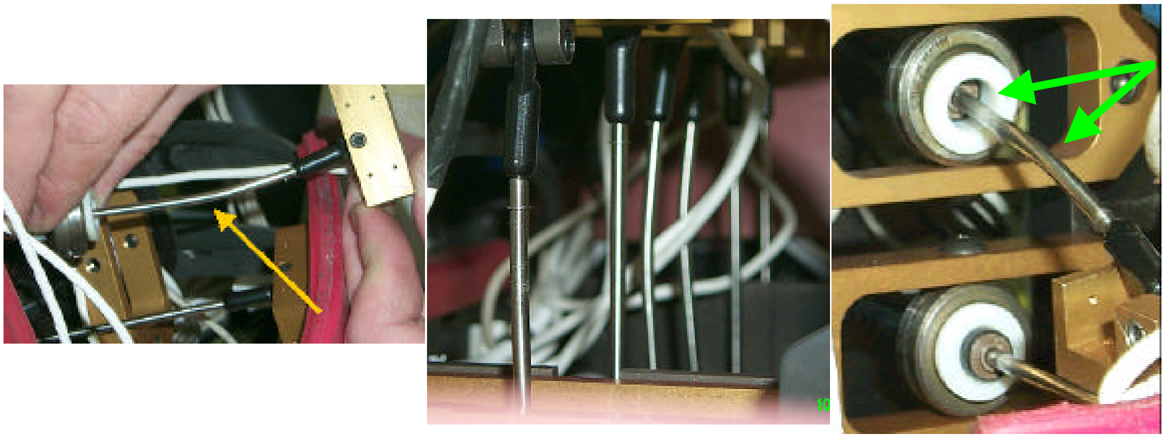


(b)



(c)

Figure 5. Bent linear potentiometer shaft (a) and gouges in rib damping material (b) after Abdomen Offset Test 243 of Sled Series I. Rib deflection data traces (c) from LRA Test 243. Note that abdomen rib 1 pot shaft bent during the test.



(a) (b) (c)

Figure 6. Bent potentiometers (a)(b)(c) and detached pot housing (c) after High-Speed Flat Wall tests with air bags.

Although no damage occurred in the flat-wall tests, the data traces in Figure 7 show that the rib deflections gradually increased with increased severity of the test conditions. The peak deflection in all flat-wall tests occurred in the first abdominal rib, likely due to the bottom of the “half-arm” intruding into the abdomen (Figure 8). In the HPF test with 400kPa foam, the first abdominal rib potentiometer reached its maximum stroke capacity of 69 mm, resulting in a “flat-top” in the data trace.

In the Padded Abdomen Offset Test (Test 521), the potentiometer shaft of abdomen rib 1 bent upward (Figure 9a). The deflection traces during Test 521 (Figure 9b) show that abdomen rib 1 reached approximately 54 mm of deflection before the bending occurred. Examination of the test setup revealed that the offset walls were not aligned vertically with the appropriate body region of the dummy. Figure 10 shows the offset abdomen plate with the original dummy seated next to the plate for illustration purposes. The abdomen plate contacts a small amount of abdomen rib 1, all of abdomen rib 2, and part of the pelvis. In Sled Series I and II, the gouges in the damping material were located on the top of the damping material of abdomen ribs 1 and 2, and the pot shafts were bent in a vertical direction. It was suspected that the misalignment of the abdomen plate caused the abdomen ribs to be loaded vertically as the dummy impacted the wall and rotated about the offset. This upward component of force imparted to the dummy resulted in the ribs moving upward, loading the rib guides vertically, and causing gouging in the damping material. As the ribs continued to deflect laterally, the ribs were able to bow out beyond the guides and move vertically. This vertical rib motion was suspected to cause the pot shafts to bend upward. It was thought that the design of the SID-IIs was such that with enough lateral deflection of the ribs, the ribs could eventually bow out beyond the rib guides, allowing the ribs to move vertically if any vertical force should be applied. The vertical force and the limited vertical motion of the potentiometer are what were suspected to cause the potentiometer shafts to bend. It was thought that if such damage occurred in a laboratory test, it is possible that it could also occur in the crash environment. Further investigation into the cause of the problem was necessary.

4.3 Upward Pendulum Test Series I

Subsequently, pendulum tests were conducted to examine the effects of upward loading on the ribs. Seven full-body calibration-type pendulum tests were conducted at 4.3-5.1 m/s using the shoulder/thorax (large) and abdomen (small) calibration probes. The dummy was tilted either 10 or 20 degrees away from the pendulum to induce an upward impact to the dummy’s shoulder, thorax and abdomen regions. Table 4 shows the Upward Pendulum Test Series I matrix. Figure 11 shows test setup photos for Tests 3 and 5.

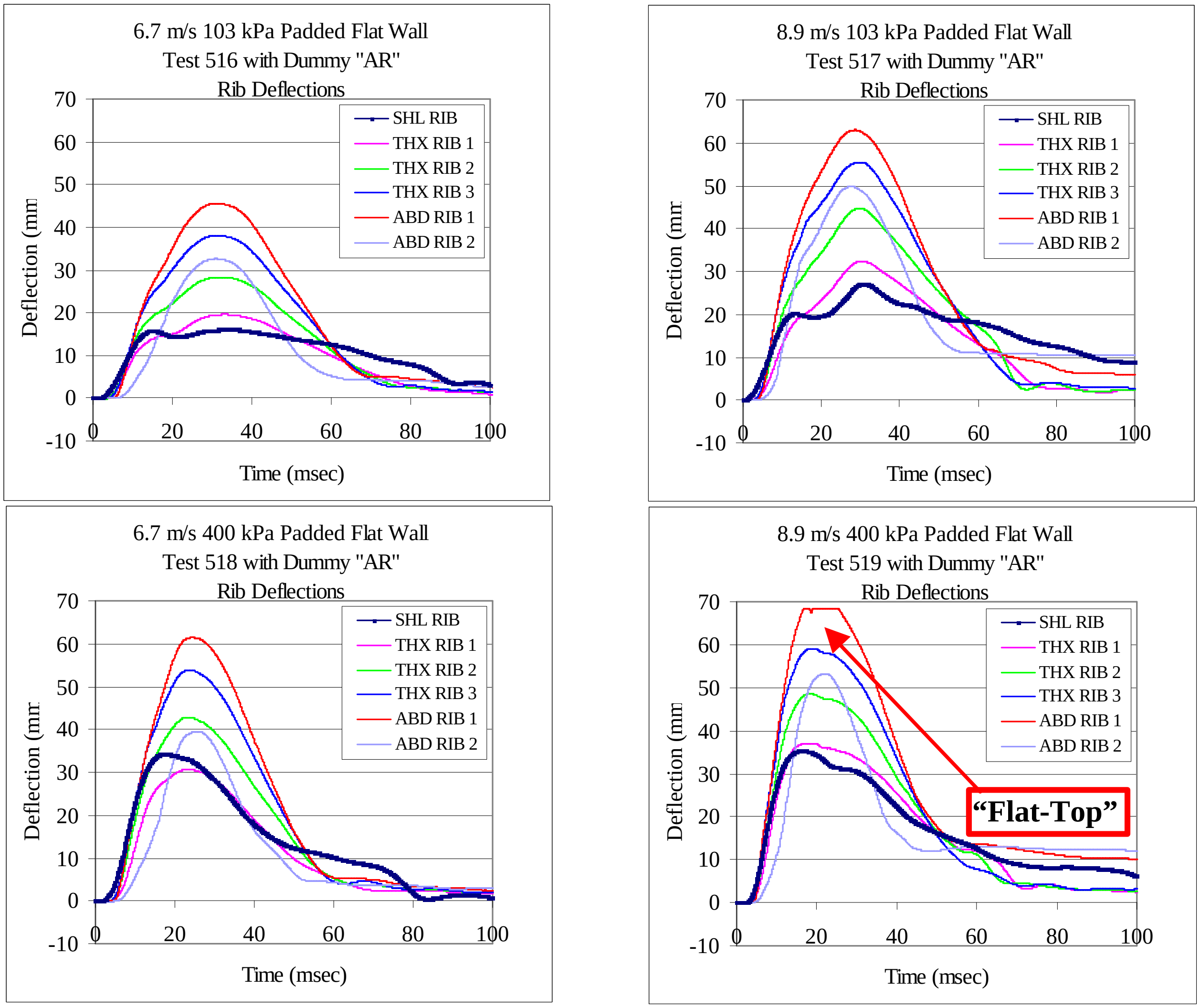


Figure 7. Sled Series II Flat Padded Wall rib deflections showing effects of impact speed and wall padding.

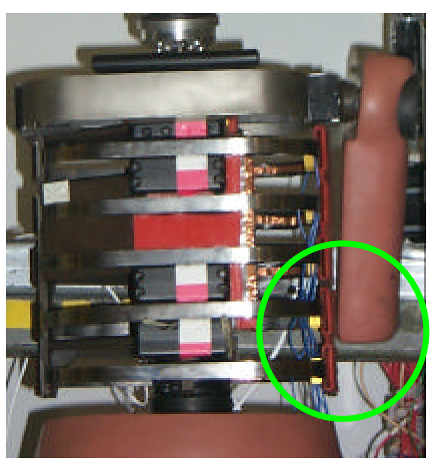
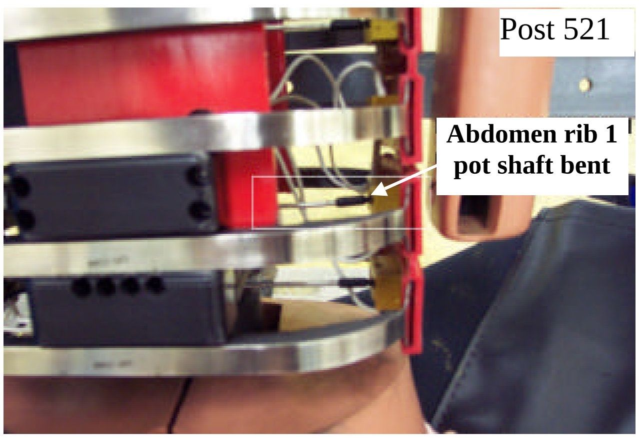
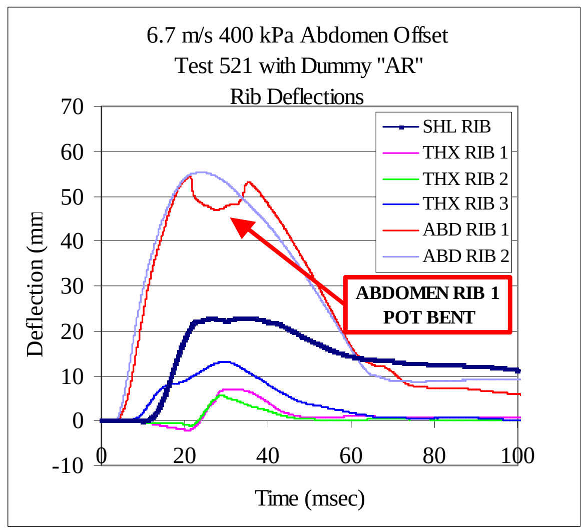


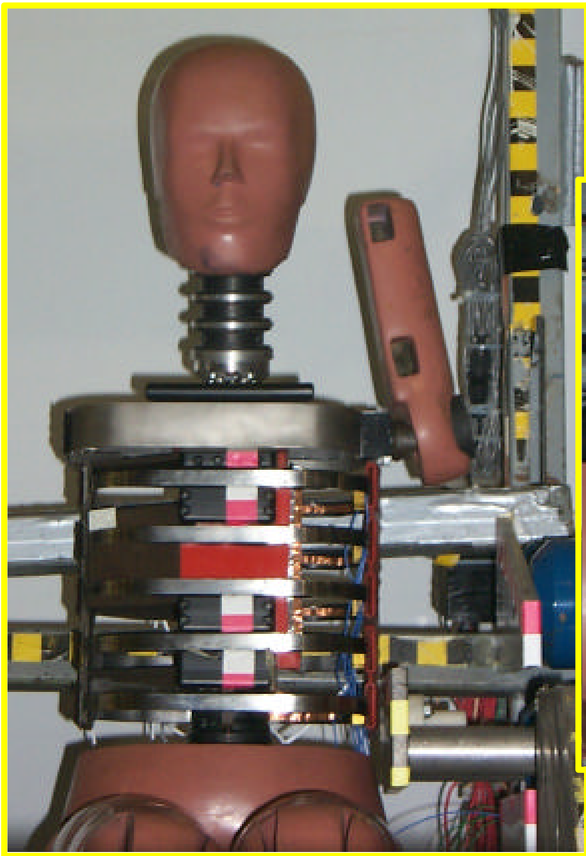
Figure 8. Bottom of half-arm ends between abdomen ribs 1 and 2; intrusion of arm into abdomen region during testing could cause abdomen rib 1 to obtain highest deflection with respect to other ribs.



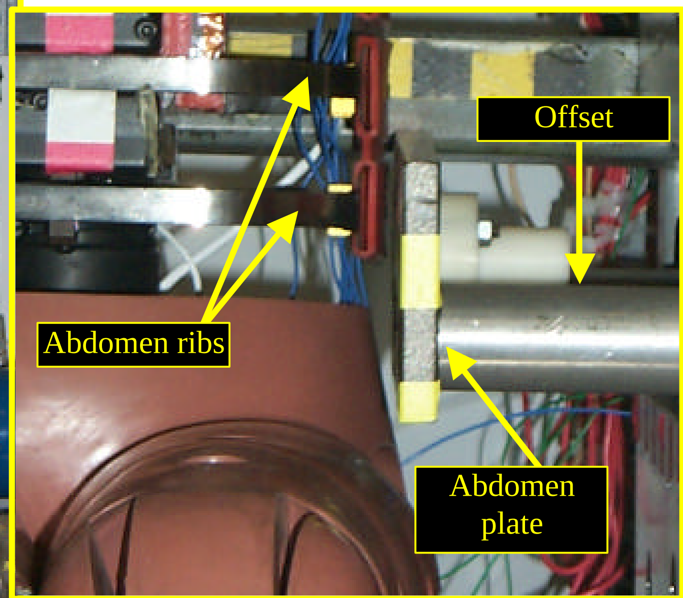


(a) (b)

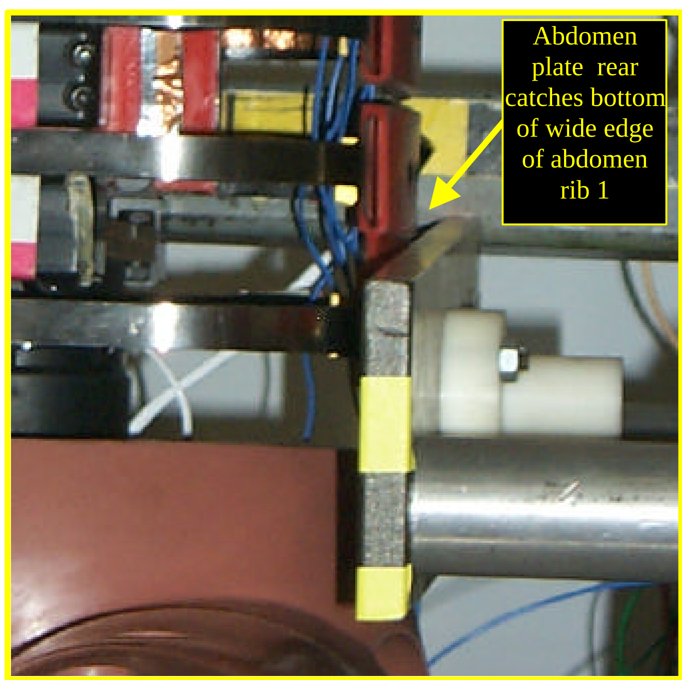
Figure 9. Bent potentiometer shaft after Padded Abdomen Offset Test 521 (a); Rib deflection traces during Test 521 with original, refurbished dummy. Note abdomen rib 1 pot bent.



(a)



(b)



(c)

Figure 10. Unaligned offset abdomen plate with Original SID-IIs dummy seated beside it to illustrate the relationship of the plate with the dummy.

Table 4. Upward Pendulum Test Series I Matrix

Impacted Region	Dummy Rotation about X axis	Probe	Impact Velocity (m/s)	Test Number	Dummy Design / Serial Number
Shoulder	10º away from probe	Small	4.50	5	AR / 020
	20º away from probe		4.86	6	
Thorax	10º away from probe	Large	4.32	2	
	20º away from probe		4.82	3	
	20º away from probe	Small	4.36	4	
			4.83	7	
Abdomen	10º away from probe	Small	4.53	1	

Small probe: 14 kg; 76.2 mm diameter face
Large probe: 14 kg; 120.65 mm diameter face
Dummy Design AR: original dummy, refurbished, with stronger adhesive between pot housings and their bushings; with jacket on

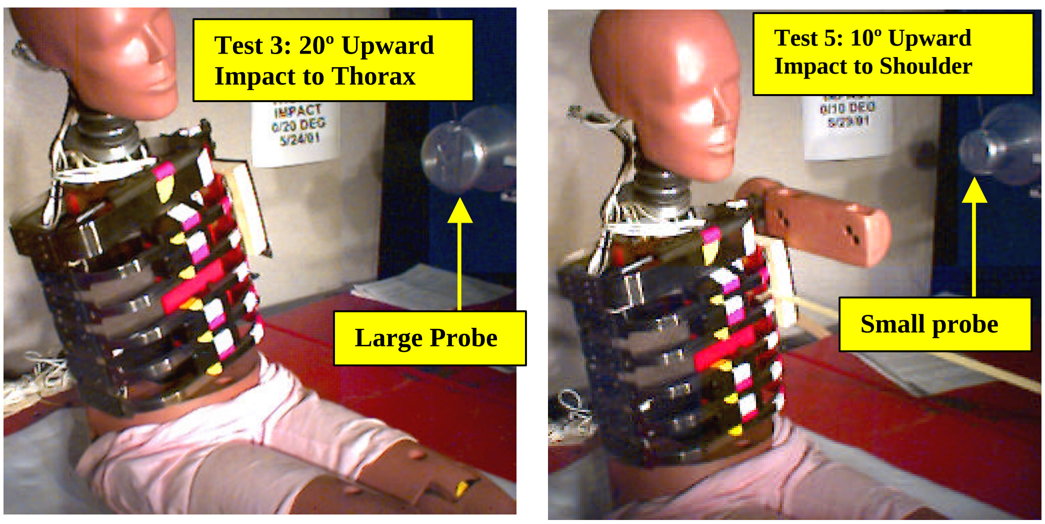


Figure 11. Setup for Tests 3 (left) and 5 (right) with large (left) and small (right) probes.

Damage to the dummy occurred in Test 3 as the edge of the large probe face became caught in the ribcage and pulled abdomen rib 1 outward laterally (Figure 12). The pot housing of abdomen rib 1 cracked and broke, which was clearly due to a test anomaly since the dummy would normally wear a jacket during a crash test. The jacket would not allow anything to get caught in the ribcage and pull the rib and pot outward. Although no damage occurred in Test 7, high-speed video showed thorax rib 2 bow out beyond the rib guide, move vertically, and catch on the rib guide (Figure 13a). This indicated that some vertical motion of the ribs was possible, without any damage. It also illustrated that the potential for damage to the potentiometer shaft existed when rib deflection and vertical forces occur. The deflection traces for thorax ribs 1, 2, and 3 during Test 7 are plotted in Figure 13b.

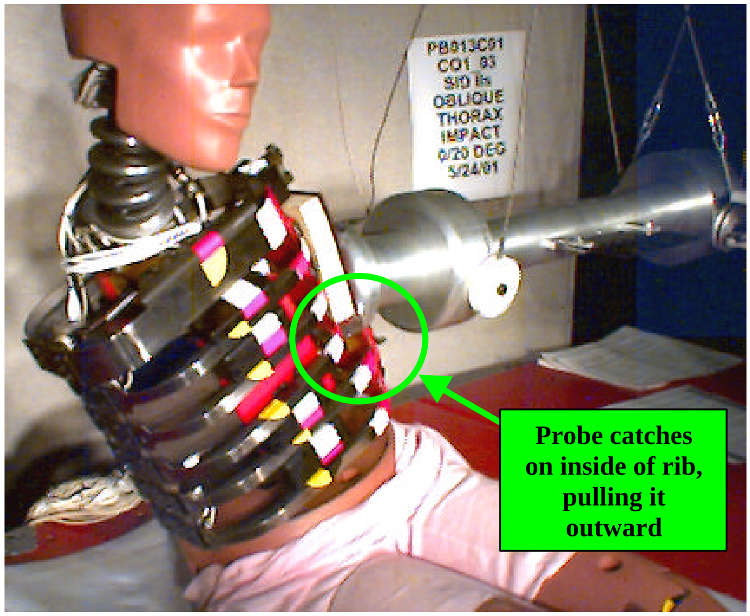
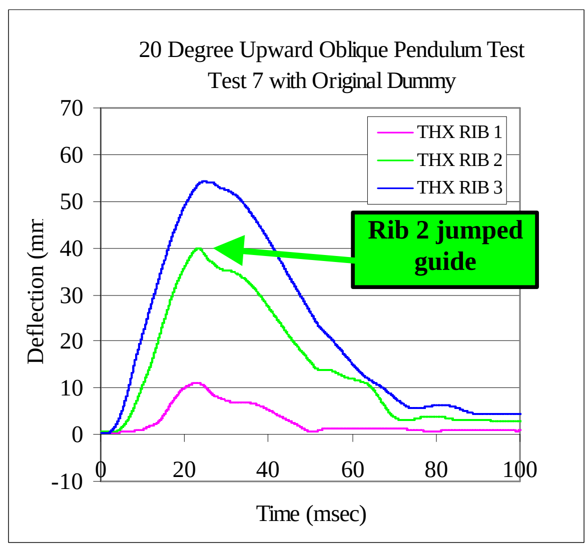


Figure 12. Large pendulum face gets caught inside abdomen rib 1 during Test 3 of Upward Pendulum Test Series I.

(a)



(b)

Figure 13. Vertical movement of ribs demonstrated in upward pendulum Test 7 (a); Deflection traces of thorax ribs 1, 2, and 3 in 20º upward oblique pendulum Test 7 with original dummy (b). Note that rib 2 (green) jumped the rib guide during the test.

4.4 Design Configuration B

FTSS was notified of the vertical movement of the ribs and resulting damage that occurred in sled tests. As a first attempt at fixing the problem, FTSS added spacers behind each rib guide to extend the guides outward $^3/_8$" (Figure 14). Also, a guide was added in the front and rear between thoracic ribs 2 and 3 because there were no guides at those locations in the dummy. With these changes to the dummy, referred to as design configuration B, further testing (Sled Series III) was conducted with the dummy's jacket removed so that rib motion could be viewed.

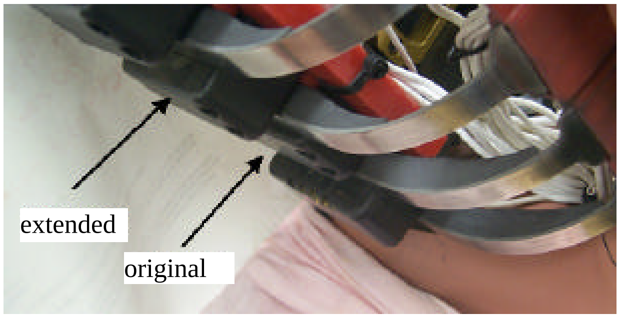


Figure 14. Extended rib guides shown with original rib guide for visual illustration.

4.5 Sled Series III

In order to determine whether the $^3/_8$" guide extensions would maintain the ribs in a horizontal plane, the original biofidelity test condition that resulted in damage was repeated: Low-Speed, Unaligned, Rigid Abdomen Offset. In order to observe the effect on the dummy of aligning the abdomen plate with the abdomen region of the dummy, one test was also performed in the Aligned plate condition (Figure 15). The impact wall, including the thorax, abdomen and pelvis plates, was raised one inch to achieve the Aligned condition. Table 5 shows the test matrix of Sled Series III, which was conducted in September 2001.

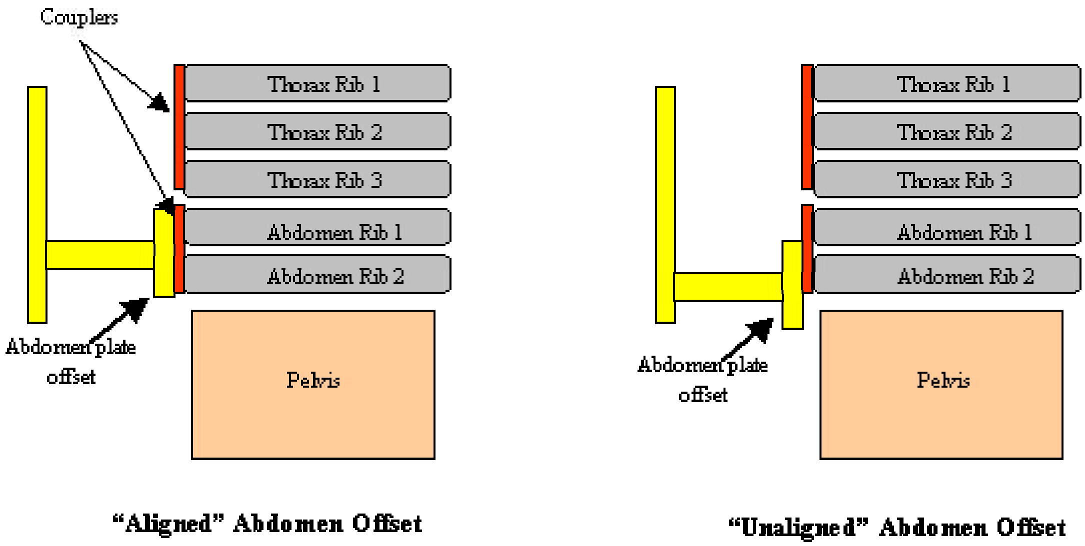


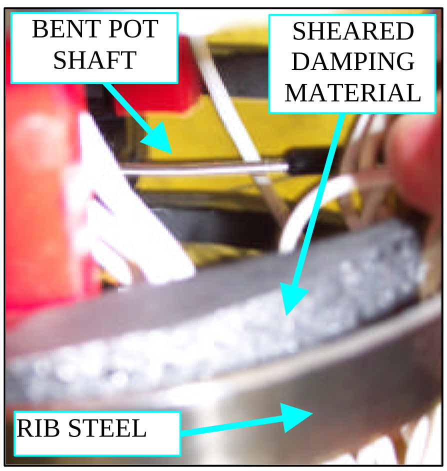
Figure 15. Schematic showing Aligned and Unaligned Abdomen Offset test configurations

Table 5. Sled Test Series III Matrix

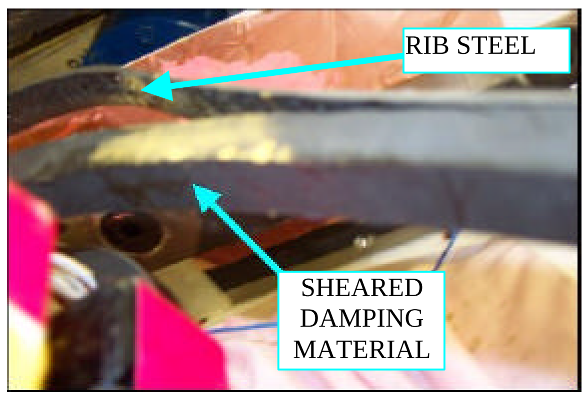
Test Conditions	Load Plate	Test Numbers	Dummy Design / Serial Number
6.7 m/s Rigid Abdomen Offset	Unaligned	642	B / 033
	Unaligned	643	B+ / 033
	Aligned	644	B / 033

Dummy Design B: additional rib guides between thorax ribs 2 & 3, in front and rear; $^{3}/_{8}$" spacers behind each rib guide; jacket removed
Dummy Design B+: all of Design B, plus extra ½" spacer behind abdomen rib 1 front guide

In the first test of Sled Series III with design B (Test 642), abdomen rib pot 1 bent severely and the damping material sheared off the rib steel, as shown in Figure 16. Motion analysis revealed that the rib jumped the guide and moved vertically, causing the damage. It appeared that the $^{3}/_{8}$" extension was not enough to maintain the ribs in a horizontal plane, so an additional ½" spacer was added behind abdominal rib guide 1 for the next test. The rib and pot were replaced. (This is referred to as design B+). The same damage was observed in Test 643: abdomen rib pot 1 bent severely and damping material sheared off the rib steel. Motion analysis showed that the rib did not jump the guide but that the rib deflected enough for the rib steel to move beyond the extra long guide. However, the rib damping material did not clear the guide, resulting in the sheared-off damping material. Deflection traces for the thorax and abdomen ribs in these two tests are shown in Figure 17.



(a)



(b)

Figure 16. Bent abdomen rib 1 potentiometer shaft (a) and separated damping material (a), (b) after Rigid Abdomen Offset Test 642 with extended rib guides.

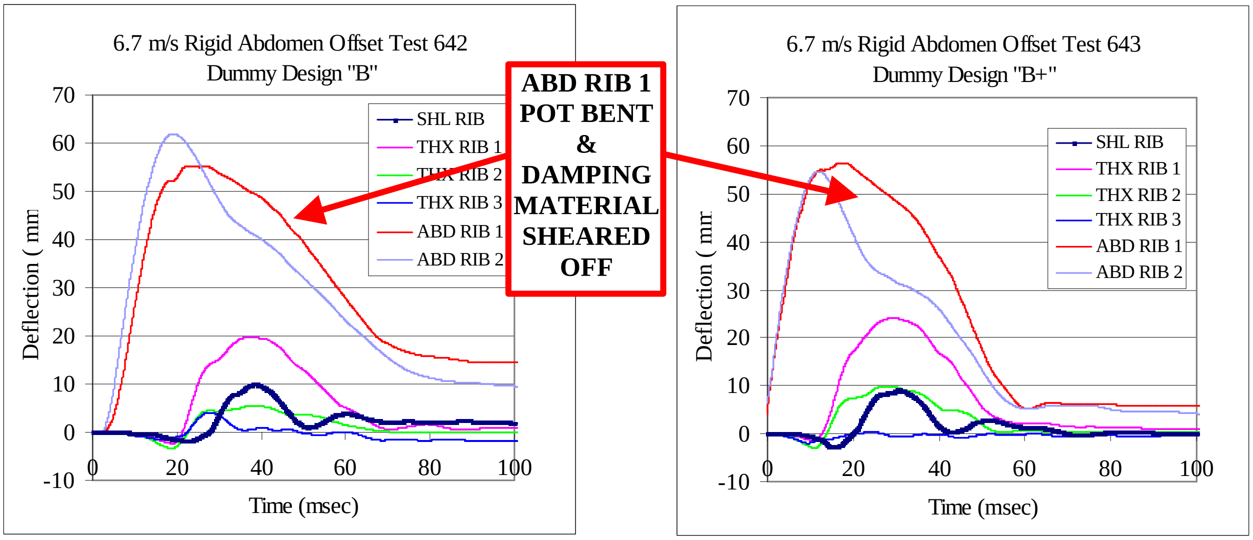


Figure 17. Rib deflections during LRA Tests 642 and 643 with $^{3}/_{8}$" and $^{7}/_{8}$" extended rib guides, respectively. Note that in both tests abdomen rib 1 pot bent and damping material sheared off.

In Test 644, the pot housing of abdomen rib 1 crushed and its shaft bent. Since this test was an Aligned configuration (Figure 15), the energy from the impact was absorbed by the two abdominal ribs, which resulted in substantial rib displacement. In the Unaligned condition, the pelvis engaged the offset abdomen plate, which may have limited the amount of deflection experienced by the abdomen ribs. In the Aligned condition, the pelvis did not contact the plate and both abdomen ribs experienced extreme deflection causing the rib stops to become engaged. The rib stops of the original design were not sufficient to protect the instrumentation from crushing or bending. Further discussion of the rib stops and Test 644 is included in Section 5, Rib Stop Modifications.

4.6 VRTC Prototype FRG

It was evident that a simple extension of the rib guides in Tests 642 and 643 would not resolve the durability issue. In order to investigate the relationship between the ribs and rib guides of the original dummy, quasi-static tests were performed on a Material Testing System (MTS) machine. The rib cage was loaded laterally by the MTS in 5mm increments, from zero to 65 mm of lateral displacement. The amount of A-P displacement to the front of thorax rib 2 and abdomen rib 1 was measured manually using a scale at each 5mm lateral displacement interval. Visual observation indicated that the thorax and abdomen ribs bow out relatively evenly toward the front and back in the A-P direction when squeezed laterally. Fitting a linear curve to the data, the amount of A-P deflection (to the front) achieved was roughly 0.5 times that of the measured lateral deflection. Figure 18 shows a photograph of the test in progress. At 2 inches of lateral deflection (Figure 18), the ribs have moved beyond the rib guides of the Original SID-IIs, allowing the ribs to move vertically if there is any force upward or downward. This demonstrates the potential for damage to the potentiometer shafts, which necessitates an improved rib guide design.

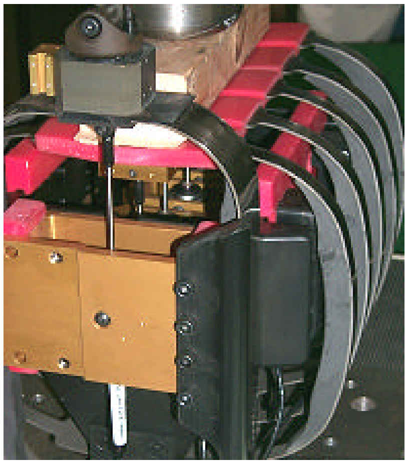


Figure 18. Quasi-static test on MTS machine to examine relationship between ribs and guides of Original SID-IIs. Ribs laterally compressed 2 inches, and ribs have bowed beyond the rib guides.

In a short period, VRTC developed and fabricated the Floating Rib Guide (FRG) design for the SID-IIs (Figures 19 & 20). In this design, when the ribs deflect laterally and expand in the anterior-posterior (A-P) direction, they contact a cover plate. Spring pins connect the cover plate and rib guides to the spine box. As the ribs deflect in the A-P direction, they contact the cover plate, forcing the guides to move away from the spine box, with the ribs, while compressing the springs behind the spine box. After deflection is complete, the springs bring the rib guides back to their original positions. Dummy skin material was glued to the posterior part of the rib guides to dampen any vibrations that might occur upon rebound of the guides to the spine box. The existing rib guide mounting holes were used to attach four spring pins per guide to the spine box for the three middle guides. The top and bottom rib guides are only attached to the cover plate and simply "float" with the others.

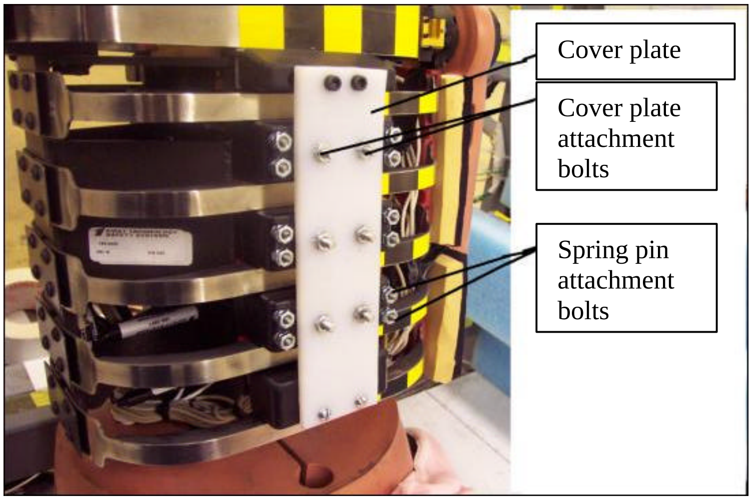


Figure 19. Photograph of the VRTC prototype Floating Rib Guide design.

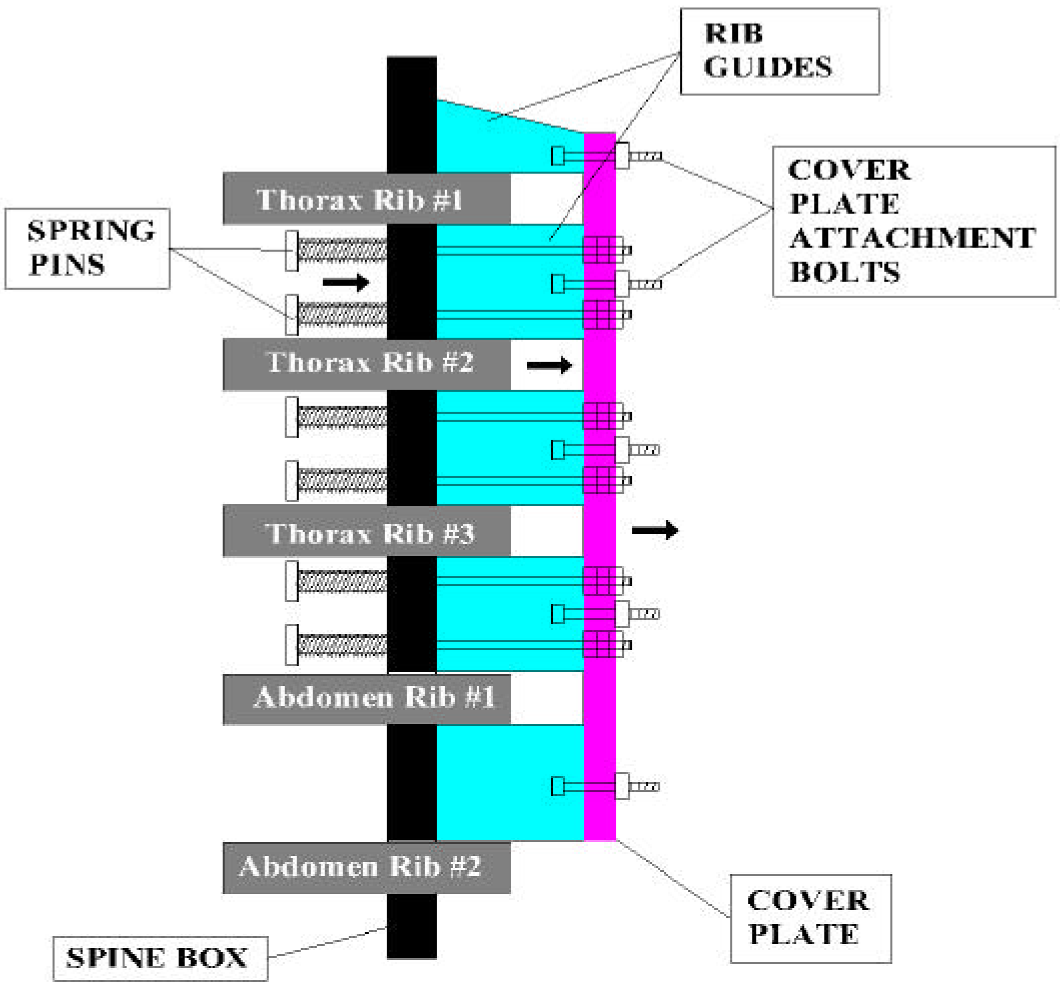


Figure 20. Schematic of the VRTC prototype Floating Rib Guide design.

It was thought that the ribs might under-ride the FRG rib guides in a situation where some of the ribs don't deflect as much as others. In other words, it was thought that it could be possible for a non-deflected rib to get caught behind a floating rib guide if the rib guide moved beyond the non-deflected rib in the A-P direction (Figure 21).

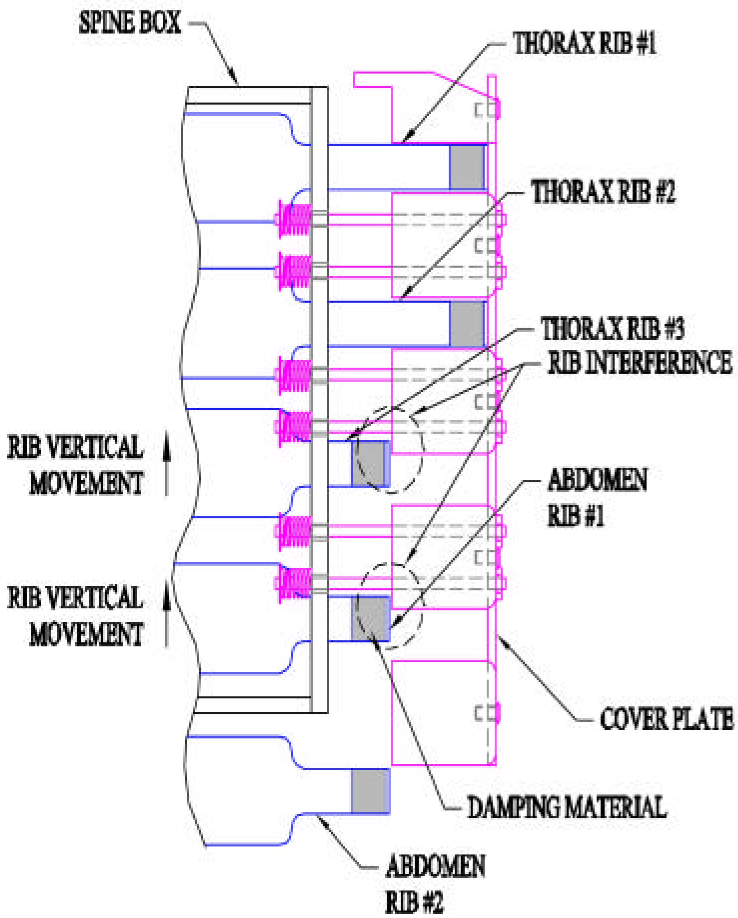


Figure 21. Schematic showing non-deflected ribs getting caught behind Floating Rib Guides. Dimensional analysis showed this to be theoretically impossible.

Since the maximum allowable amount of lateral deflection is 69mm, the maximum frontal A-P deflection would be roughly 34.5mm. Figure 22(a) shows a schematic of the FRG system at rest. It was determined that the ribs contact the cover plate of the FRG system at 21mm of frontal A-P deflection (Figure 22b). After 21mm A-P deflection to contact the cover plate, only 13.5 mm of allowable frontal A-P deflection remain. The rib guides (with the $^{3}/_{8}$"spacers) are 39.5mm wide. In order for a rib guide to move forward enough to allow a non-deflecting rib to get caught behind it, the deflecting rib (moving the rib guide) would have to move 21 mm to contact the cover plate, plus an additional 18.5 mm in the frontal A-P direction. Since there are only 13.5mm of available rib deflection remaining after 21mm of A-P deflection, the ribs cannot under-ride the rib guides, as there would be a 5mm overlap between the rib and guide (Figure 22c).

4.7 Possible Noise in FRG

Certification tests were performed by VRTC to examine the possibility that the multiple-part FRG could cause extraneous noise in the dummy data. Unfiltered, certification test data traces for thorax rib 2 during Thorax Impact tests with the Original and FRG dummies (Figure 23a) show that both designs exhibit responses with high frequency content throughout the test. The filtered (FIR 100, the OSRP-recommended filter for this channel) thorax rib acceleration data traces for the same tests show very comparable responses without noise (Figure 23b). As the high frequency data is filtered out as it should be, no noise problem in either dummy is apparent.

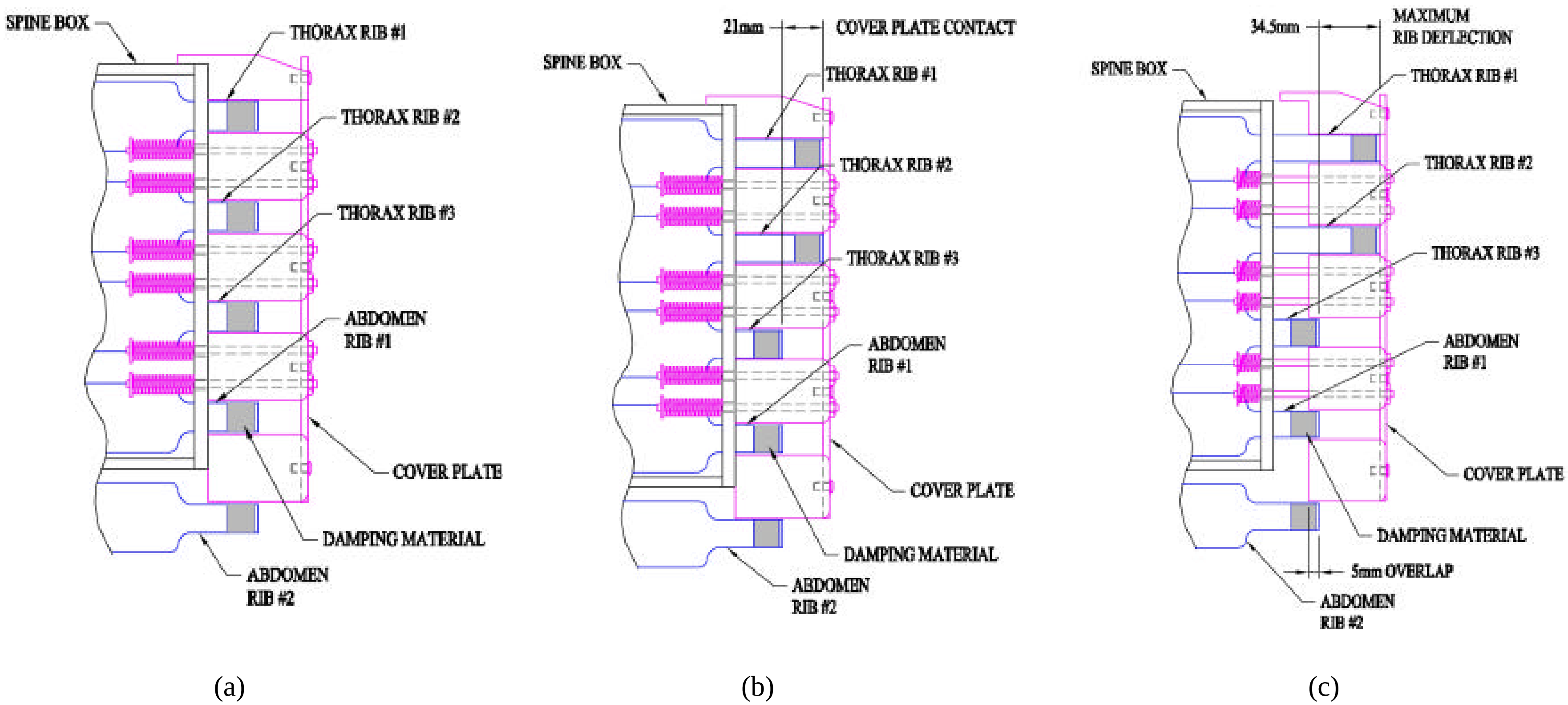
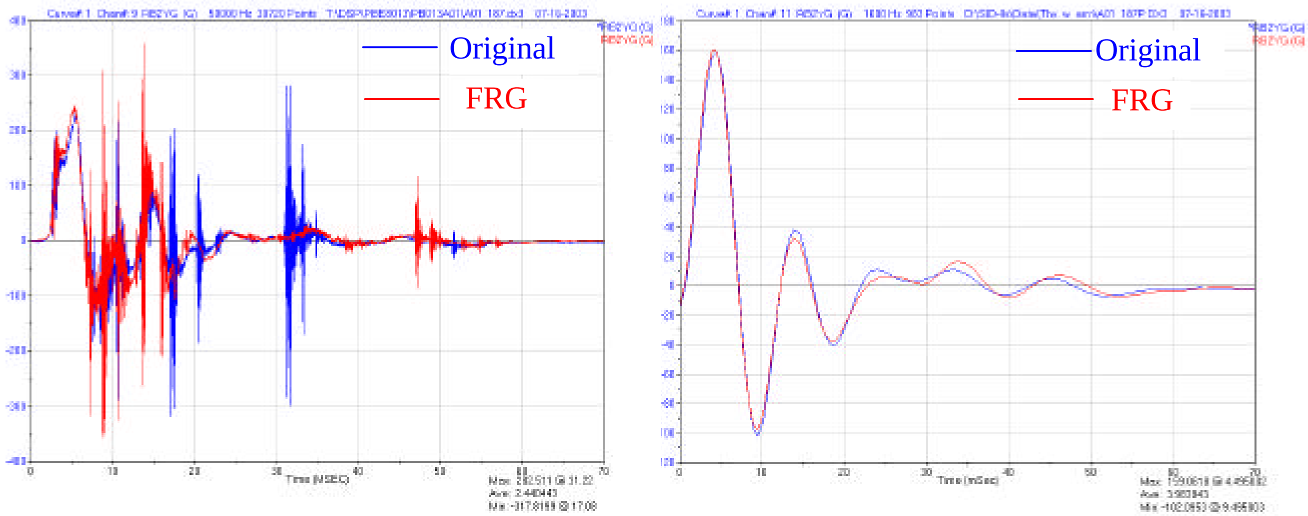


Figure 22. Schematics showing FRG system (a) at rest; (b) as thorax ribs 1 and 2 contact cover plate; and (c) at maximum deflection of thorax ribs 1 and 2. Note that in (c), 5mm of overlap exist between the non-deflected ribs and the floating rib guides for a maximum rib deflection of 69mm, indicating that rib under-ride is not possible.



(a) (b)

Figure 23. (a) Unfiltered and (b) Filtered (FIR 100) thorax rib 2 lateral acceleration data traces for Test 187 with the Original dummy and Test 190 with the FRG dummy.

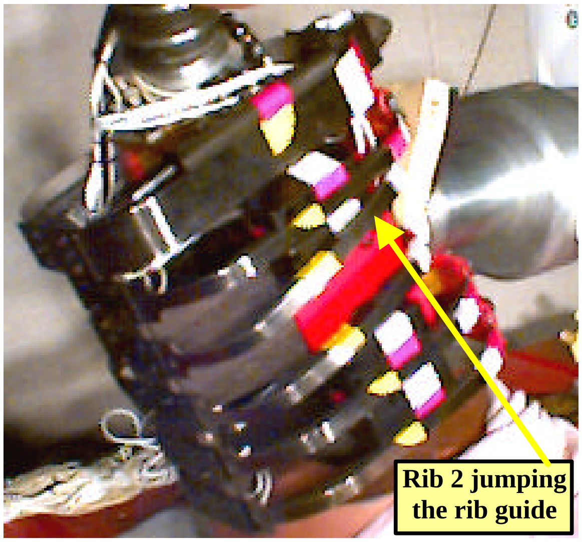
4.8 Upward Pendulum Test Series II

In order to determine the effectiveness of the FRG prototype modification at limiting vertical motion of the ribs, the pendulum tests with the dummy tilted away from the pendulum were conducted in the configuration where vertical rib motion was observed with the original dummy. Table 6 shows the matrix for the Upward Pendulum Test Series II, which was conducted in October 2001. Design D has $^{3}/_{8}$"spacers behind each guide, an extra guide in the front and back between thoracic ribs 2 & 3, and the prototype FRG system designed by VRTC.

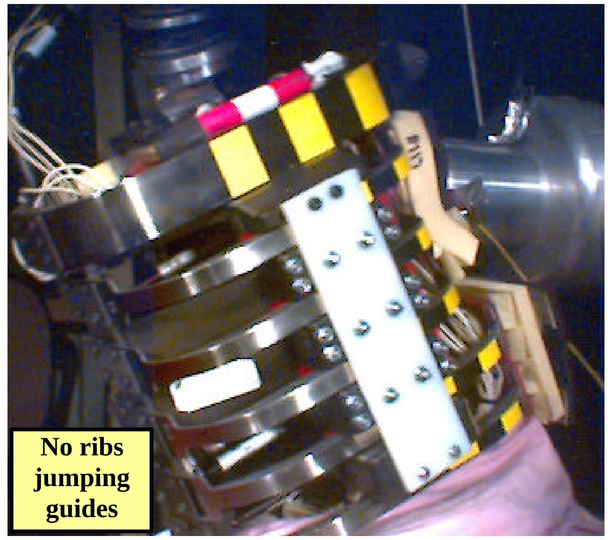
Table 6. Upward Pendulum Test Series II Matrix

<table>
<tr><th>Impacted Region</th><th>Dummy Rotation about X axis</th><th>Dummy Rotation about Z axis</th><th>Probe</th><th>Impact Velocity (m/s)</th><th>Test Number</th><th>Dummy Design / Serial Number</th></tr>
<tr><td rowspan="3">Thorax</td><td rowspan="2">20º away from probe</td><td rowspan="2">0º</td><td rowspan="3">Small</td><td>5.08</td><td>191</td><td rowspan="3">D / 033</td></tr>
<tr><td>5.12</td><td>192</td></tr>
<tr><td>0º</td><td>20º towards probe</td><td>4.29</td><td>196</td></tr>
<tr><td colspan="7"><u>Small probe</u>: 14 kg; 76.2 mm diameter face
<u>Dummy Design D</u>: additional rib guides between thorax ribs 2 & 3, in front and rear;
$^{3}/_{8}$"spacers behind each rib guide; VRTC prototype FRG; jacket removed</td></tr>
</table>

The pendulum tests showed that the FRG system was successful at keeping the ribs from jumping the guides. Figure 24 shows the original dummy rib 2 jumping its rib guide (a) in Upward Pendulum Test Series I (Test 7), and FRG dummy D with no ribs jumping any guides (b) during Upward Pendulum Test Series II (Test 191).



(a)



(b)

Figure 24. (a) Original dummy rib 2 jumping its rib guide during 20º upward pendulum Test 7 (Series I); and (b) FRG dummy D with no ribs jumping any guides during Test 191 (Series II).

4.9 Sled Series IV

To examine the effects of the FRG system, sled tests were conducted in November 2001 with the VRTC prototype FRG dummy (design D). Table 7a shows the test matrix for Sled Series IV, which aimed to determine whether the FRG system would prevent damage and not significantly alter the response of the dummy. Some of the tests of Series IV were selected in order to compare the results with those of previous tests. Tests of Series IV were also designed to make direct comparisons between designs B and D. Table 7b shows the tests of Series IV along with similar tests previously performed, with the test conditions, dummy design and damage noted.

Table 7a. Sled Test Series IV Matrix

Test Conditions	Offset Plate	Test Numbers	Dummy Design/Serial Nos.
6.7 m/s padded abdomen offset (2" 103 kPa)	Not aligned	713	D / 033
6.7 m/s padded abdomen offset (2" 103 kPa)	Aligned	711	B / 033
6.7 m/s padded abdomen offset (2" 103 kPa)	Aligned	715	D / 033
6.7 m/s rigid flat wall	Aligned	716	D / 033
8.9 m/s padded flat wall (4" 103 kPa)	Aligned	712	B / 033
8.9 m/s padded flat wall (4" 103 kPa)	Aligned	717	D / 033
Dummy Design B: additional rib guides between thorax ribs 2 & 3, in front and rear; $^{3}/_{8}$"spacers behind each rib guide; jacket removed **Dummy Design D:** Design B, plus VRTC prototype FRG			
(yellow / cyan)	Comparison tests		

Table 7b. Sled Test Damage Summary Organized by Test Type

Speed & Impact Wall Configuration	Wall Aligned with Abdomen Ribs?	Rigid or Padded	Test #	Dummy Design	Jacket on?	Damage
6.7 m/s Abdomen Offset	No	Rigid	243	A	Yes	Abdomen rib 1 pot bent; ribs deformed; abdomen ribs 1,2 damping material gouged
		3" 400 kPa	521	AR		Abdomen rib 1 pot bent
		Rigid	642	B	No	Abdomen rib 1 pot bent and damping material sheared off
			643	B+		Abdomen rib 1 pot bent and damping material sheared off
		2" 103 kPa	713	D		Shoulder damage
6.7 m/s Abdomen Offset	Yes	Rigid	644	B	No	Abdomen rib 1 pot bent; housing crushed
		2" 103 kPa	711	B		None
			715	D		None
6.7 m/s Flat Wall	No	Rigid	238	A	Yes	None
			239			None
			240			None
	Yes		716	D	No	None
8.9 m/s Flat Wall	No	4" 103 k Pa	517	AR	Yes	None
	Yes		712	B	No	None
			717	D		None

Dummy Design A: original dummy with jacket on
Dummy Design AR: original dummy, refurbished, with jacket on
Dummy Design B: additional rib guides between thorax ribs 2 & 3, in front and rear; $^{3}/_{8}$"spacers behind each rib guide; jacket removed
Dummy Design B+: Design B, plus extra ½" spacer behind abdomen rib 1 front guide
Dummy Design D: Design B, plus VRTC prototype FRG

In order to assess the effectiveness of the FRG design in the Unaligned Abdomen Offset condition, a single test (713) was conducted with dummy configuration D. As all previous tests of this condition resulted in damage to the dummy (see Table 7b), conducting a comparison test with version A or B of the dummy did not seem practical. In order to provide a direct comparison, Abdomen Offset Tests 711 and 715 were conducted with dummy configurations B and D, respectively, with the abdomen offset plate aligned with the dummy's abdomen region. The only difference between dummies B and D is that D has the VRTC FRG prototype design. Due to objections from the OSRP that the test conditions used thus far had been unrealistic and severe, softer padding (103kPa vs. 400kPa or rigid wall previously used) was added to the impact wall in all of the abdomen offset tests in this series. Figure A1 in Appendix A shows comparison data traces from Tests 711 and 715 for documentation purposes.

A Low-Speed Rigid Flat Wall Test (716) was conducted with dummy D to assess the performance of the FRG design in this condition. High-Speed Padded (4" 103 kPa) Flat Wall Tests 712 and 717 were conducted with dummies B and D, respectively, in order to assess whether or not the FRG changed the response of the dummy. Figure A2 in Appendix A shows comparison data traces from Tests 712 and 717.

4.9.1 Results

In the Unaligned Abdominal Offset Test (713), with softer padding reducing the severity of the test, damages to the dummy's abdomen that were seen previously with the original dummy in Unaligned Abdominal Offset tests (see Table 7b) were not observed in the dummy with the FRG prototype modifications. It is not known whether the dummy modifications or the reduced severity tests prevented the damage. In order to affirm that the FRG is effective, a test in the rigid condition would need to be conducted. However, in Test 713 with dummy D, damage to the *shoulder* region occurred. It appeared that the FRG prototype had resolved the rib-jumping problem of the thorax and abdomen, but that the shoulder would also need some modification to prevent damage as well. Further discussion of the shoulder modification is included in Section 5, Shoulder Modifications.

In the Aligned Abdomen Offset Test 644 of Sled Series III, the abdomen pot housing crushed and pot shaft bent due to insufficient rib stops (see Table 7b). This test condition was performed again in Series IV, with soft padding (103 kPa), in Tests 711 and 715 with dummies B and D, respectively, both having the original rib stops. As neither dummy sustained any damage in these tests, the padding apparently reduced the test severity adequately. These tests were conducted to observe the effects of the prototype FRG in an aligned offset condition.

Table 7c shows peak values and the percent difference for the peak measurement of dummy D compared to that of dummy B for the comparison tests 711 and 715. Table 7c and Figure A1 in Appendix A show that the peak pelvis load, T12 and pelvis accelerations are reduced 16-22% with the FRG in the Aligned, Padded Abdomen Offset test condition. All other peaks and curve shapes appear comparable.

Table 7c. Sled Test Series IV Comparison Peak Values – Aligned LPA (Tests 711, 715)

Measurement	Dummy	Peak Value	% Difference
Thorax Plate Force (N)	B	1930	0
	D	1930	
Abdomen Plat Force (N)	B	8050	-10.7
	D	7190	
Pelvis Plate Force (N)	B	2840	-21.1
	D	2240	
T1 Lateral Acceleration (g)	B	32.3	7.4
	D	34.7	
T12 Lateral Acceleration (g)	B	48.9	-21.7
	D	38.3	
Pelvis Lateral Acceleration (g)	B	61.2	-16.0
	D	51.4	
Abdomen Rib 1 Deflection (mm)	B	70	-3.3
	D	68	

In the LRF test condition (Test 716), the FRG dummy did not sustain any damage. As the load wall was slightly higher with respect to the dummy as compared to Tests 238-240 (see Table 7b) and the dummy had its jacket removed, no direct comparison of dummy responses was made.

Table 7d shows peak values and the percent difference for the peak measurement of dummy D compared to that of dummy B for the comparison HPF Tests 712 and 717. Table 7d and Figure A2 in Appendix A show that the dummy acceleration and deflection data traces between dummies B and D are quite similar, with peak differences below 3.3%. The dummy appears to load the impact wall comparably in the thorax and abdomen regions; however, the pelvis load is slightly larger with the FRG (29% at peak). Repeatability and reproducibility with the SID-IIs have not been evaluated and it is not known whether the pelvis (and abdomen) regions load the wall repeatably in this test setup.

Table 7d. Sled Test Series IV Comparison Peak Values – HPF (Tests 712, 717)

Measurement	Dummy	Peak Value	% Difference
Thorax Plate Force (N)	B	6070	5.8
	D	6420	
Abdomen Plat Force (N)	B	2910	-8.2
	D	2670	
Pelvis Plate Force (N)	B	5770	28.6
	D	7420	
T1 Lateral Acceleration (g)	B	42.8	0.7
	D	43.1	
T12 Lateral Acceleration (g)	B	61.7	2.9
	D	63.5	
Pelvis Lateral Acceleration (g)	B	66.4	2.0
	D	67.7	
Abdomen Rib 1 Deflection (mm)	B	70	-3.2
	D	68	
		Flat-topped	

In summary, Series IV showed that with softer padding added to the Unaligned Abdominal Offset Tests (713, 715), reducing the severity of the tests, damages to the dummy's abdomen that were seen previously with the original dummy in Abdominal Offset tests (see Table 7b) were not observed in the dummy with the FRG prototype modifications. In order to affirm that the FRG is effective, rigid offset tests would need to be conducted. However, the FRG does respond somewhat differently than previous dummy designs of the SID-IIs. The primary differences are reduced pelvis load and T12 and pelvis accelerations in the Aligned Abdomen Offset condition as well as increased pelvis plate force in the HPF condition.

4.10 Sled Series V

Sled Series V was conducted in January 2002 in order to examine the performance of the latest design, denoted "E", which included all prototype modifications. Dummy E consisted of the extra rib guides between ribs 2 and 3, 3/8" spacers behind each guide, the VRTC prototype FRG system in the thorax and abdomen, improved rib stops from FTSS and a VRTC prototype shoulder guide. The test matrix of Sled Series V included tests to evaluate each modification type (Table 8a). The tests to be discussed here are highlighted in yellow. In order to achieve greater confidence in the ability of the FRG system to prevent damage and not change the response of the dummy significantly, Low-Speed, Unaligned, Padded (2" 103 kPa foam) and Rigid, Abdomen Offset tests (described in more detail in Section 4.5, Sled Series III) with dummy E were conducted. The rib stop and shoulder modifications are discussed in the corresponding sections of this report. The Neck and Shoulder Biofidelity Tests were conducted to assess the shoulder modifications and are discussed in Section 5, Shoulder Modifications. The Aligned conditions were also tested with dummy E and are discussed in Section 6, Rib Stop Modifications.

Table 8a. Sled Test Series V Matrix (FRG Modification Evaluation)

Test Conditions	Offset Plate	Test Numbers	Dummy Design / Serial Number
6.7 m/s Padded Abdomen Offset (2" 103 kPa)	Unaligned	777	E / 033
6.7 m/s Rigid Abdomen Offset		778	E / 033
6.7 m/s Rigid Abdomen Offset	Aligned	779	E / 033
		780	E w/jacket on / 033
6.7 m/s Rigid Thorax Offset	Aligned	781	E / 033
		784	C / 033
ISO 9790 Neck Test 3/Shoulder Test 3	n/a	782	E / 033
		783	C / 033
<u>Dummy Design C</u>: additional rib guides between thorax rib 3 and abdominal rib 1, in front and rear; 3/8" spacers behind each rib guide; improved rib stops from FTSS; jacket removed **<u>Dummy Design E</u>:** additional rib guides between thorax ribs 2 & 3, in front and rear; 3/8" spacers behind each rib guide; improved rib stops from FTSS; VRTC prototype FRG; VRTC prototype shoulder guide; jacket removed			

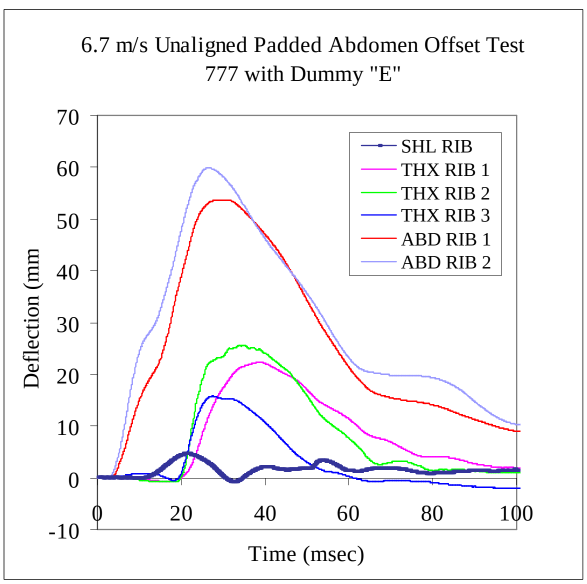
Table 8b shows a summary of the damage observed in Unaligned Abdomen Offset Sled tests throughout the dummy evaluation. Tables 2, 3, 5, 7a and 8a are referenced in Table 8b for each corresponding sled series discussed in the report. No damage occurred in Tests 777 and 778, demonstrating that the FRG durability surpassed that of the original SID-IIs (design A) by preventing out-of-plane rib motion and damage to the dummy.

Deflection data traces for the two tests are shown for documentation purposes in Figure 25a. Figure 25b (a) and (b) shows comparison data traces for abdomen ribs 1 and 2 from Test 243 with the Original SID-IIs (dummy A) and Test 778 with dummy E. These two tests were both Unaligned, Rigid Abdomen Offset tests. Dummy A sustained a bent abdomen rib 1 potentiometer shaft, deformed ribs and gouged damping material of abdomen ribs 1 and 2. Dummy E sustained no damage. The data traces show similar paths up to the peak deflection of dummy A, then, the modified dummy (E) achieves more abdomen deflection than the original dummy (A) (55mm vs. 42mm for abdomen rib 1 and 56mm vs. 47mm for abdomen rib 2). The increase in deflection is due to the ribs of the FRG dummy staying in a horizontal plane, thus allowing the pots to move and measure further in the y direction, rather than moving out of plane, and incurring damage as with dummy A. The shift in time of the data traces is likely due to positioning of the dummy prior to the test.

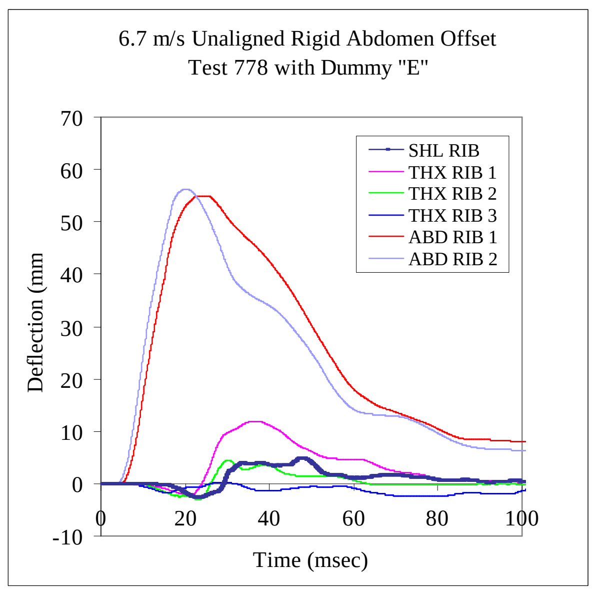
Table 8b. Unaligned Abdomen Offset Sled Test Damage Summary

Speed & Impact Wall Configuration	Rigid or Padded	Wall Aligned with Abdomen Ribs?	Test #	Sled Series / Table #	Dummy Design	Jacket on?	Damage
6.7 m/s Abdomen Offset	Rigid	No	243	I / 2	A	Yes	Abd rib 1 pot bent; ribs deformed; abd ribs 1,2 damping material gouged
	3” 400 kPa		521	II / 3	AR		Abd rib 1 pot bent
	Rigid		642	III / 5	B	No	Abd rib 1 pot bent and damping material sheared off
			643	III / 5	B+		Abd rib 1 pot bent and damping material sheared off
	2” 103 kPa		713	IV / 7a	D		Shoulder damage
	2” 103 kPa		777	V / 8a	E		None
	Rigid		778	V / 8a	E		None

Dummy Design A: original dummy with jacket on
Dummy Design AR: original dummy, refurbished, with jacket on
Dummy Design B: additional rib guides between thorax ribs 2 & 3, in front and rear; 3/8” spacers behind each rib guide; jacket removed
Dummy Design B+: Design B, plus extra ½” spacer behind abdomen rib 1 front guide
Dummy Design D: Design B, plus VRTC prototype FRG
Dummy Design E: additional rib guides between thorax ribs 2 & 3, in front and rear; 3/8” spacers behind each rib guide; improved rib stops from FTSS; VRTC prototype FRG; VRTC prototype shoulder guide; jacket removed

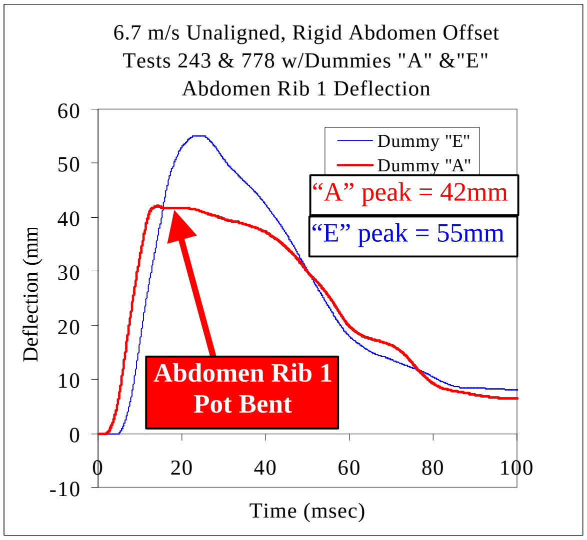


(a)

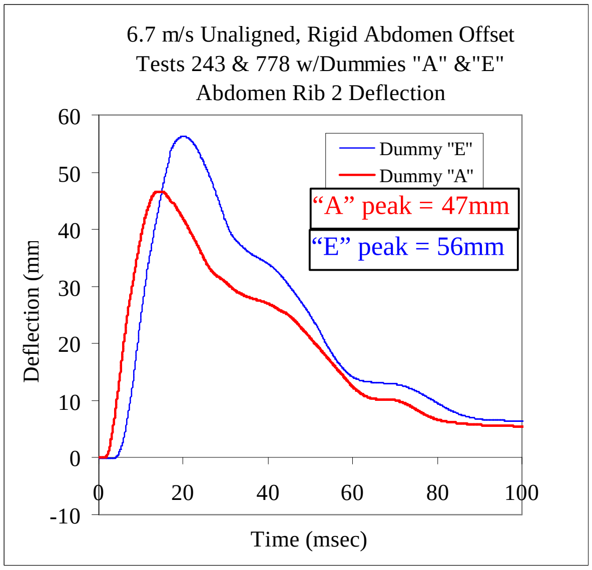


(b)

Figure 25a. Rib deflection data traces during Padded and Rigid Unaligned Abdomen Offset Tests 777 (a) and 778 (b), respectively. Note that no damage occurred in these two tests with dummy E.



(a)



(b)

Figure 25b. Abdomen rib 1 (a) and 2 (b) deflection data traces during Rigid, Unaligned Abdomen Offset Tests 243 and 778, with dummies A and E, respectively. Note that no damage occurred during Test 778 with Dummy E and that dummy A had the jacket on.

4.11 Summary of FRG Design Concept

After observing consistent damage in the Original SID-IIs during the VRTC evaluation, VRTC determined that the dummy's durability needed to be improved, requiring the dummy's design to be modified. An attempt was made to increase the depth of the rib guides of the Original SID-IIs in order to prevent damage to the dummy and instrumentation. Not only did the increased guide depth yield bent potentiometer shafts as seen with the Original design, but damping material was sheared off as well. It was evident that a more sophisticated modification was necessary. After examining the mechanism of damage and the relationship of the ribs and guides of the Original design, VRTC developed and fabricated the Floating Rib Guide system. As vertical movement of the ribs was responsible for the damage to the dummy, the FRG system prevents the ribs from leaving the horizontal plane with guides that "float" with the ribs as they expand in the A-P direction. The FRG design proved to be effective at preventing damage to the instrumentation and ribs. However, the response of the FRG appeared to show some differences when compared to the Original dummy such as reduced T12 and pelvis measurements in the Aligned LRA condition and increased pelvis loads in the HPF condition.

At the February 2002 OSRP meeting, VRTC presented the results of Sled Series V to the OSRP, and FTSS agreed to improve upon VRTC's FRG design concepts. In June 2002, VRTC received a prototype FRG from FTSS. For simplicity, the FTSS prototype design of the SID-IIs dummy is referred to as the FRG dummy even though it includes shoulder and rib stop modifications in addition to the Floating Rib Guide design. (The next two sections of the report discuss modifications to the shoulder and rib stops. Discussion of the evaluation of the FTSS prototype FRG is continued in Section 7, FTSS FRG Prototype Evaluation.)

5. Shoulder Modifications

The shoulder region of the dummy also experienced several durability problems throughout the dummy evaluation. The cause of the damage appeared to be vertical motion of the shoulder rib, similar to the vertical motion of the ribs in the thorax and abdomen regions. The original dummy's shoulder rib guide (Figure 26) was not sufficient to keep the shoulder rib in a horizontal plane and prevent damage. In Figure 2, "Timeline of Critical Events in the Evaluation of the Original SID-IIs," the column labeled Shoulder corresponds to this section of the report. The damages observed in the shoulder region are summarized chronologically below.

(a) (b)

Figure 26. Side view (a) and oblique frontal view (b) of the original shoulder rib, damping material and shoulder rib guide.

5.1 Sled Series II

The first indication that the shoulder region of the dummy needed modification was in May 2001 during Test 522 of Sled Series II (see Table 3). This series of tests was conducted with padding in response to industry concerns that the rigid offset tests were too severe for the SID-IIs dummy. During the Low-Speed Padded Pelvis Offset (LPP) test (Figure 27) with three inches of 400kPa foam and the original, refurbished dummy (AR), the shoulder pot bent and damping material was gouged (Figure 28). The potentiometer bent vertically at the junction between the metal rod and the rod end bearing that secures the pot end to the rib. The damping material was gouged by the rear shoulder rib guide as the rib moved vertically. Motion analysis showed that the dummy's arm, which was positioned horizontally at 90º to the front of the dummy, went over the top of the thorax load plate. As the dummy rotated into the wall, the thorax plate loaded the shoulder under the arm vertically (Figure 29), causing the damage. The rib deflection data is shown in Figure 30.

5.2 OOP Airbag I

The damage in the LPP test was considered a test anomaly until similar damages occurred in out-of-position (OOP) air bag Test F01_218 in September 2001. The OOP tests were being conducted as part of a cooperative effort of the ISO Technical Working Group (ISOTWG) whose task was to evaluate side air bag aggressiveness using the SID-IIs dummy. In this particular OOP test, the dummy's thorax was positioned against the 2000 BMW 528i right front side air bag module and the arm was positioned 90º forward (Figure 31a). These tests were designed to maximize the exposure of the dummy to the air bag as outlined in ISOTWG procedures. Damages to the shoulder from this test included permanent rib deformation, slipped pot housing, separated damping material, and a bent potentiometer shaft (Figure 31b,c). The rib deflection data traces are shown in Figure 32. The damage pattern from the OOP test and high-speed video clearly indicated that vertical motion of the shoulder rib caused the damage.

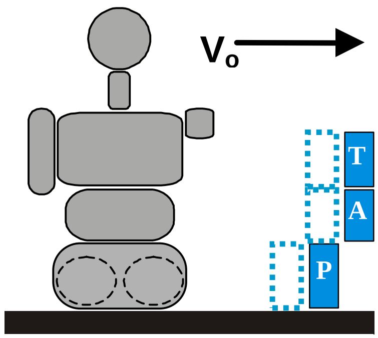


Figure 27. LPP test setup schematic.

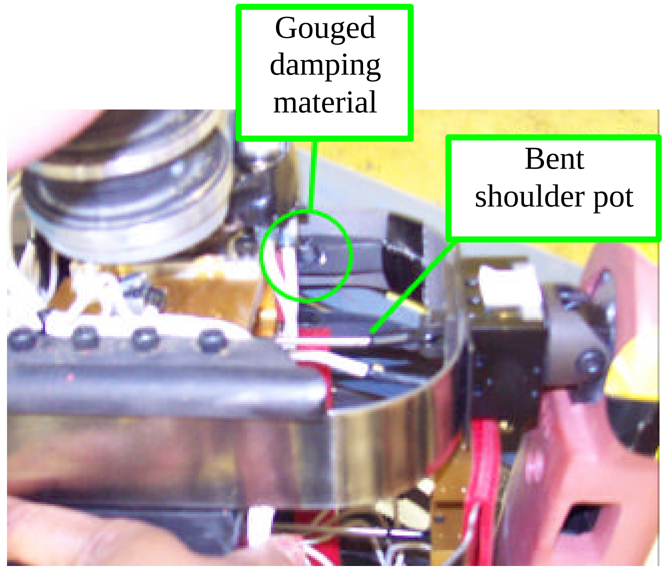


Figure 28. Gouged damping material and bent shoulder pot after Padded Pelvis Offset Test 522.

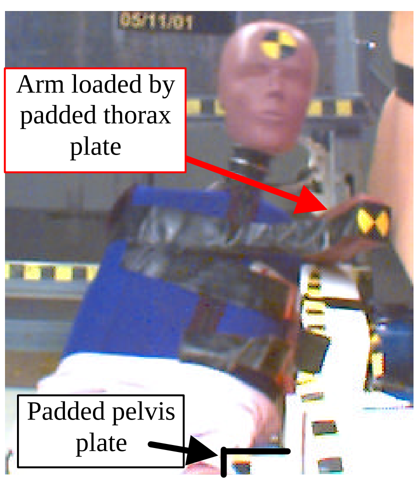


Figure 29. Arm is loaded by padded thorax plate during Test 522.

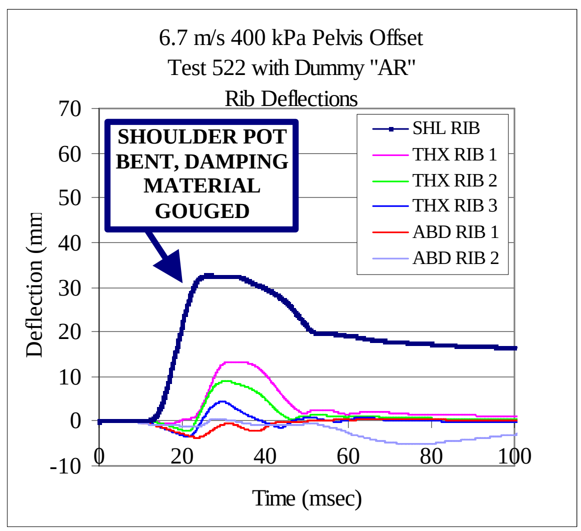


Figure 30. Rib deflection traces during 6.7 m/s Padded Pelvis Offset Test 522 with original, refurbished dummy. Note shoulder pot bent and shoulder damping material gouged.

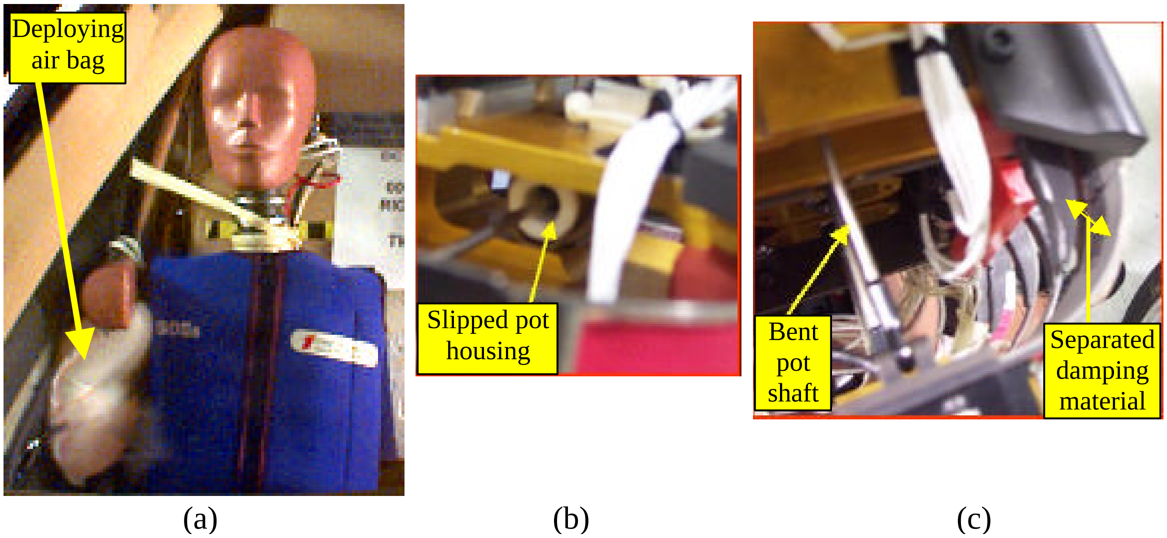


Figure 31. OOP airbag test photo (a); post-test damage: slipped pot housing (b), bent pot shaft and separated damping material (c).

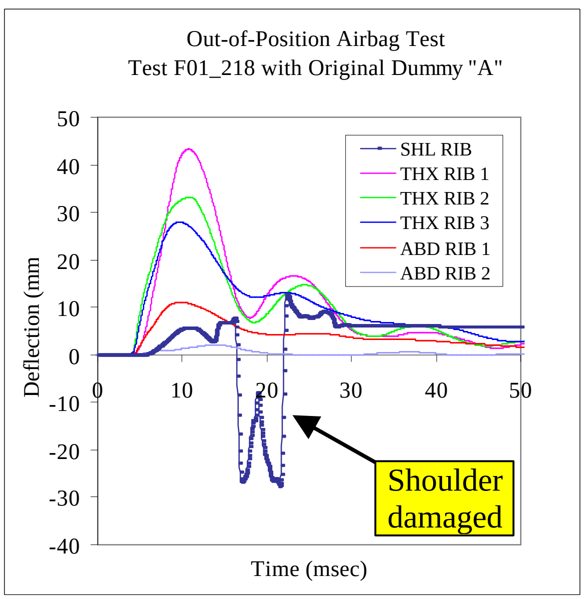


Figure 32. Rib deflection traces during OOP airbag test F01_218 with the original dummy design. Note that the shoulder sustained severe damage.

5.3 Sled Series IV

Further evidence that the shoulder required modification occurred in November 2001 during Sled Series IV. This test series was conducted to evaluate the new VRTC prototype FRG system that was designed to resolve vertical motion resulting in pot bending in the thorax and abdomen. In the Unaligned, Padded (2" 103 kPa foam) Abdominal Offset Test 713 (Table 6a) with dummy D, the shoulder rib became lodged over the neck mounting bracket, the shoulder pot rod bent and damping material separated from the rib steel (Figure 33). High-speed video showed the kinematics of the dummy to be similar to those of Test 522, where the arm and shoulder went over the thorax plate, which then loaded the shoulder vertically (Figure 34). Rib deflection data traces are shown in Figure 35 for documentation purposes. It was quite evident that the shoulder rib guide was ineffective and would require modification. Table 9 summarizes the damages observed in the shoulder region of the dummy.

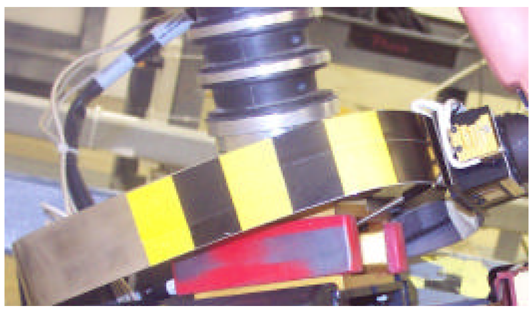
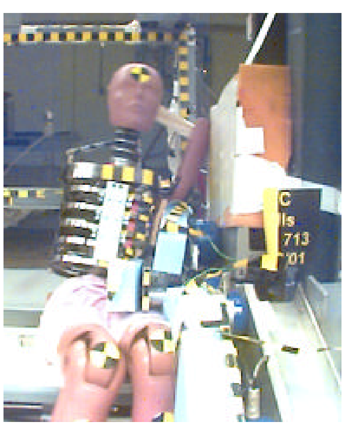
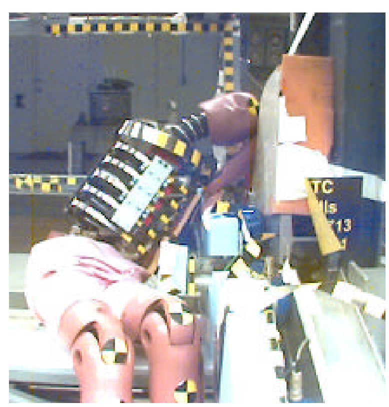


Figure 33. Shoulder rib lodged up over neck mounting bracket and bent potentiometer after 6.7 m/s Unaligned Padded Abdomen Offset (2" 103 kPa) Test 713.



27 msec after dummy impacts abdomen plate

37 msec after dummy impacts abdomen plate



116 msec after dummy impacts abdomen plate

Figure 34. High-speed video sequence during Test 713 at 27, 37 and 116 msec after dummy impacts abdomen offset plate. Shoulder appears to be vertically loaded by thorax plate interaction with arm.

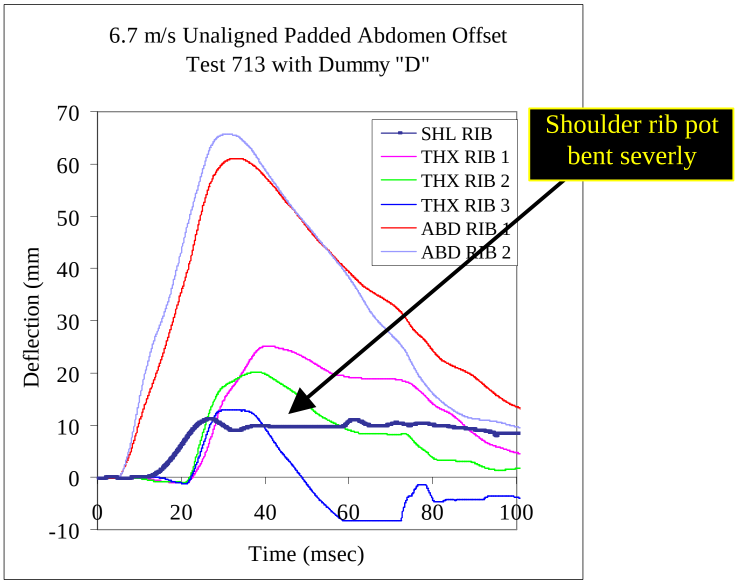


Figure 35. Rib deflection data traces during Test 713 showing unusual activity in the shoulder rib and thorax rib 3

Table 9. Shoulder Damage Observations

Test Conditions	Test #	Test Series/ Table #	Dummy Design	Damage
6.7 m/s Padded Pelvis Offset (3" 400kPa)	522	Sled II/3	AR	Shoulder pot bent
Out-of-Position Airbag in 2000 BMW 528i	F01_218	OOP I/na	AR	Shoulder rib deformed; shoulder pot bent; damping material separated; pot housing inset
6.7 m/s Padded (2" 103 kPa), Unaligned, Abdomen Offset	713	Sled IV/7a	D	Shoulder pot bent; damping material separated
Dummy Design AR: original dummy, refurbished; jacket on **Dummy Design D:** additional rib guides between thorax ribs 2 & 3, in front and rear; 3/8" spacers behind each rib guide; VRTC prototype FRG; jacket removed				

5.4 VRTC Prototype Shoulder "Clavicle" Guide

In December 2001 VRTC designed and fabricated a prototype shoulder "clavicle" guide (Figure 36). The guide mounted in the existing shoulder guide holes and consisted of a 6 $^{5}/_{8}$" long aluminum rod with a $^{5}/_{8}$" diameter at the mounting end and a $^{3}/_{8}$" diameter at the guiding end. The prototype guide had a 2 $^{1}/_{2}$" long x $^{3}/_{8}$" inner diameter x $^{5}/_{8}$" outer diameter Teflon cover over the aluminum rod at the guiding end. The guiding end of the prototype clavicle guide was designed such that no metal-to-metal contact would occur and that the diameter of the guiding end could be optimized for desired allowance of vertical movement of the shoulder.

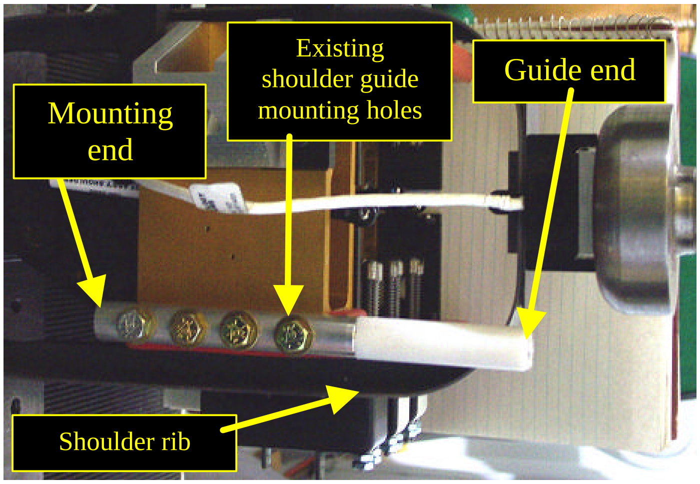


Figure 36. Top view of VRTC prototype shoulder "clavicle" guide.

5.5 Shoulder Impactor Series I

In order to assess the effectiveness of the VRTC prototype shoulder guide, Shoulder Impactor Series I was conducted in January 2002. The tests were intended to (1) study the displacement of the shoulder in order to ascertain where the clavicle rib guide could be located so as not to interfere with the lateral motion of the shoulder and to (2) investigate whether the clavicle rib guide concept would eliminate or reduce the vertical motion of the shoulder rib during a shoulder impact.

The SID-IIs spine was mounted rigidly on a steel pedestal with the thoracic ribs removed, leaving only the shoulder rib to absorb the energy of the impact. The height of the centerline of the impactor was aligned with the center of the black rubber insert of the left shoulder of the SID IIs. The impactor (34.9 kg) was traveling at approximately 1.1 m/s at impact. The speed of the impact was established to stroke the shoulder rib approximately 44 mm laterally.

The shoulder rib potentiometer recorded displacement and the shoulder load cell recorded the lateral, anterior and vertical applied force at the shoulder. Overhead digital video photographic images were recorded at 500 frames per second. A photo target was placed on top of the load cell and ¼-inch photo tape was positioned on the clavicle guide and on the spine top surface to aid in approximate displacement measurement.

Table 10 shows the six tests performed. The direction of impact was controlled through a 15^{o} wooden impact face that was attached to the impactor face in the appropriate orientation to provide upward, forward, rearward, or upward and forward or upward and rearward directions of applied force.

Table 10. Shoulder Impactor Series I Test Matrix

Test No.	Nominal Impact Speed	Direction of Impact
1	1.1 m/s	Flat
2	1.1 m/s	15^{o} Forward
3	1.1 m/s	15^{o} Rearward
4	1.1 m/s	15^{o} Upward
5	1.1 m/s	15^{o} Upward & 15^{o} Forward
6	1.1 m/s	15^{o} Upward & 15^{o} Rearward

In no case did any dummy structure, such as the arm, strike the clavicle rib guide. The shoulder rib did not move vertically out of the plane of the original undeformed position. In the three tests with upward applied force (Tests 4, 5 and 6), the upper edge of the shoulder rib gouged the Teflon bearing surface of the clavicle rib guide and in some cases peeled a small thin curl of Teflon away from the clavicle. At the end of testing, the clavicle rib guide was very slightly deformed from bending in the upward direction. Table 11 shows approximate displacements of the shoulder relative to the clavicle guide in the video images.

Table 11. Approximate Shoulder Rib Displacement

Test No.	Direction of Impact	Lateral Displacement (mm)	Anterior Displacement (mm)	Posterior Displacement (mm)
1	Flat	44.5	-	-
2	15^{o} Forward	38.1	25.4	-
3	15^{o} Rearward	41.3	-	25.4
4	15^{o} Upward	34.9	-	-
5	15^{o} Upward & 15^{o} Forward	34.9	19	-
6	15^{o} Upward & 15^{o} Rearward	38.1	-	22

The concept of a clavicle shoulder rib guide to control vertical movement of the shoulder appeared to be viable. Although these tests exhibited less than maximum displacement (approximately 45 mm versus 65 mm max.) there was no indication of the shoulder leaving the horizontal plane (although in all cases the deformed shoulder rib had exceeded the A-P dimension of the original SID-IIs shoulder guide). The use of a straight rod as a shoulder rib guide also appeared viable since no contacts between the shoulder structures and the rod were observed. It is possible that under more severe impact conditions, where larger shoulder displacements would occur, that a dummy structure, such as the arm, might contact the clavicle; however, this appeared unlikely; it would be possible to shorten the length of the clavicle and/or relocate it to avoid this occurrence. The gouging and peeling of the Teflon indicated that a harder bearing material would be needed for the clavicle-to-shoulder contact surface.

Possible improvements, which were not implemented, could have included optimizing the shape, as well as the location, of the clavicle to provide effective vertical motion control and reduce the possibility of undesirable contact with dummy structures. In addition, other clavicle materials could also be investigated to avoid metal-to-metal contact and provide a hard bearing surface. A stronger clavicle shape or material might also be desirable to eliminate permanent deformation in bending.

In general this concept of a clavicle shoulder rib guide to control vertical motion appeared to be effective and feasible. It was likely that it could have been incorporated into the SID-IIs dummy design without affecting response, weight or physical dimensions.

5.6 Sled Series V

In January 2002, Sled Series V was conducted to examine the performance of the latest design (dummy E), which included VRTC prototype shoulder guide and FRG and FTSS prototype rib stops. The test matrix of Sled Series V included tests to evaluate each modification type (Table 12). The tests to be discussed here are highlighted in yellow. One test each of ISO Neck Test 3 (and Shoulder Test 3) (ISO, 1999) with dummies C and E was performed to determine whether the latest modifications had affected the biofidelity of the neck and shoulder. Two Unaligned, Abdomen Offset tests (described in Section 4.5) with dummy E were performed to assess the shoulder modification's ability to prevent damage to the shoulder as seen in Series IV, Test 713 (see Table 9). Dummy C consisted of the extra rib guides, 3/8" spacers behind each guide, and improved rib stops from FTSS. Dummy E consisted of design C, plus the VRTC prototype FRG system in the thorax and abdomen, and the VRTC prototype shoulder guide. The rib stops and Aligned tests are discussed in Section 6, Rib Stop Modifications.

Table 12. Sled Test Series V Matrix (Shoulder Modification Evaluation)

Test Conditions	Offset Plate	Test Numbers	Dummy Design / Serial Number
6.7 m/s Padded Abdomen Offset (2” 103 kPa)	Unaligned	777	E / 033
6.7 m/s Rigid Abdomen Offset		778	E / 033
6.7 m/s Rigid Abdomen Offset	Aligned	779	E / 033
		780	E w/jacket on / 033
6.7 m/s Rigid Thorax Offset	Aligned	781	E / 033
		784	C / 033
ISO Neck Test 3/Shoulder Test 3	n/a	782	E / 033
		783	C / 033

Dummy Design C: additional rib guides between thorax rib 3 and abdominal rib 1, in front and rear; 3/8” spacers behind each rib guide; improved rib stops from FTSS; jacket removed
Dummy Design E: additional rib guides between thorax ribs 2 & 3, in front and rear; 3/8” spacers behind each rib guide; improved rib stops from FTSS; VRTC prototype FRG; VRTC prototype shoulder guide; jacket removed

5.6.1 ISO Neck/Shoulder Tests

The ISO test procedure (ISO, 1999) calls for the subject to be positioned between two boards in order to support the dummy during translation of the sled and to restrict upper torso rotation (Figure 37) and the top of the sideboard to be 40 to 50 mm below the top of the dummy’s shoulder. A rope was used to secure the dummy to the seat. The sled was accelerated to 22 +/- 0.5 km/h with a pulse that was within the corridor shown in Figure 38.

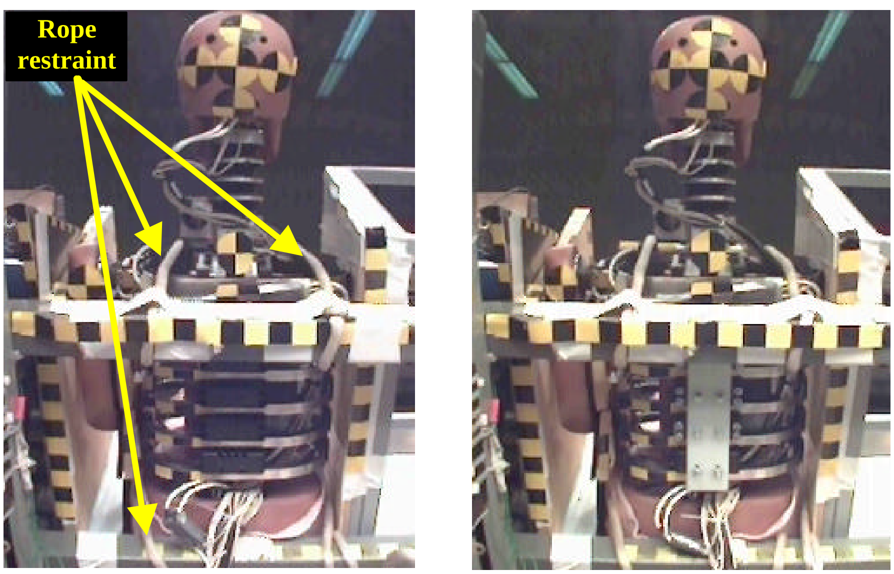


Figure 37. ISO Neck Test 3 and Shoulder Test 3 set up for tests 783 with dummy C (left) and 782 with dummy E (right).

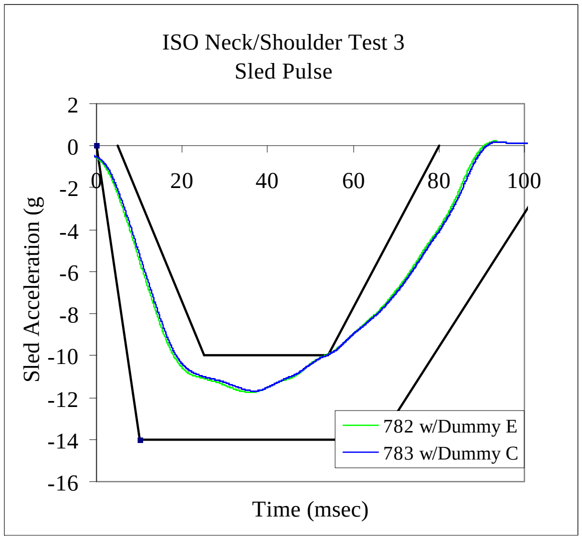


Figure 38. ISO Neck/Shoulder Test 3 Sled Acceleration Input Corridor with sled acceleration data from Tests 782 and 783 with dummies E and C, respectively.

All measurements from the ISO Neck and Shoulder Test were quite similar, indicating that the prototype designs by VRTC were not affecting the dummy's neck and shoulder biofidelity responses (Table 13). Bold type in Table 13 indicates those measurements that were not within the scaled biomechanical targets (Scherer et al, 1998). Peak lateral acceleration of the head cg and peak twist angle for both designs C and E were below the biomechanical response targets. Note that the peak horizontal displacement of the head cg relative to the sled, peak flexion angle, and peak twist angle (highlighted in yellow) are measurements taken from video motion analysis. Select data traces from the neck and shoulder regions of the dummy (Figure 39) show almost identical traces when comparing responses from dummies C and E. The modifications made to dummy E do not appear to affect the neck and shoulder response or biofidelity, as compared to design C.

Table 13. ISO Neck Test 3 and ISO Shoulder Test 3 Results

Scaled Biomechanical Response Targets	Units	Lower Bound	Upper Bound	SID-IIs E	SID-IIs C
Peak lateral acceleration of head cg	g	21	39	**15**	**14**
Peak horizontal displacement of head cg relative to sled	mm	151	185	178	174
Peak flexion angle	deg	68	82	70	72
Peak twist angle	deg	62	75	**35**	**35**
Peak lateral acceleration of T1	g	14	19	17	17

5.6.2 Unaligned Abdomen Offset Tests

Since severe damage occurred in Test 713 of Sled Series IV with dummy D (Table 9, "Shoulder Damage Observations"), the same Unaligned, Padded (2" 103kPa) Abdomen Offset test condition was used with dummy E (Test 777), which had the VRTC shoulder rib guide modification, to evaluate the ability of the shoulder modification to prevent damage. An Unaligned, Rigid Abdomen Offset test (Test 778) was also run with dummy E to further examine the performance of the prototype shoulder clavicle guide.

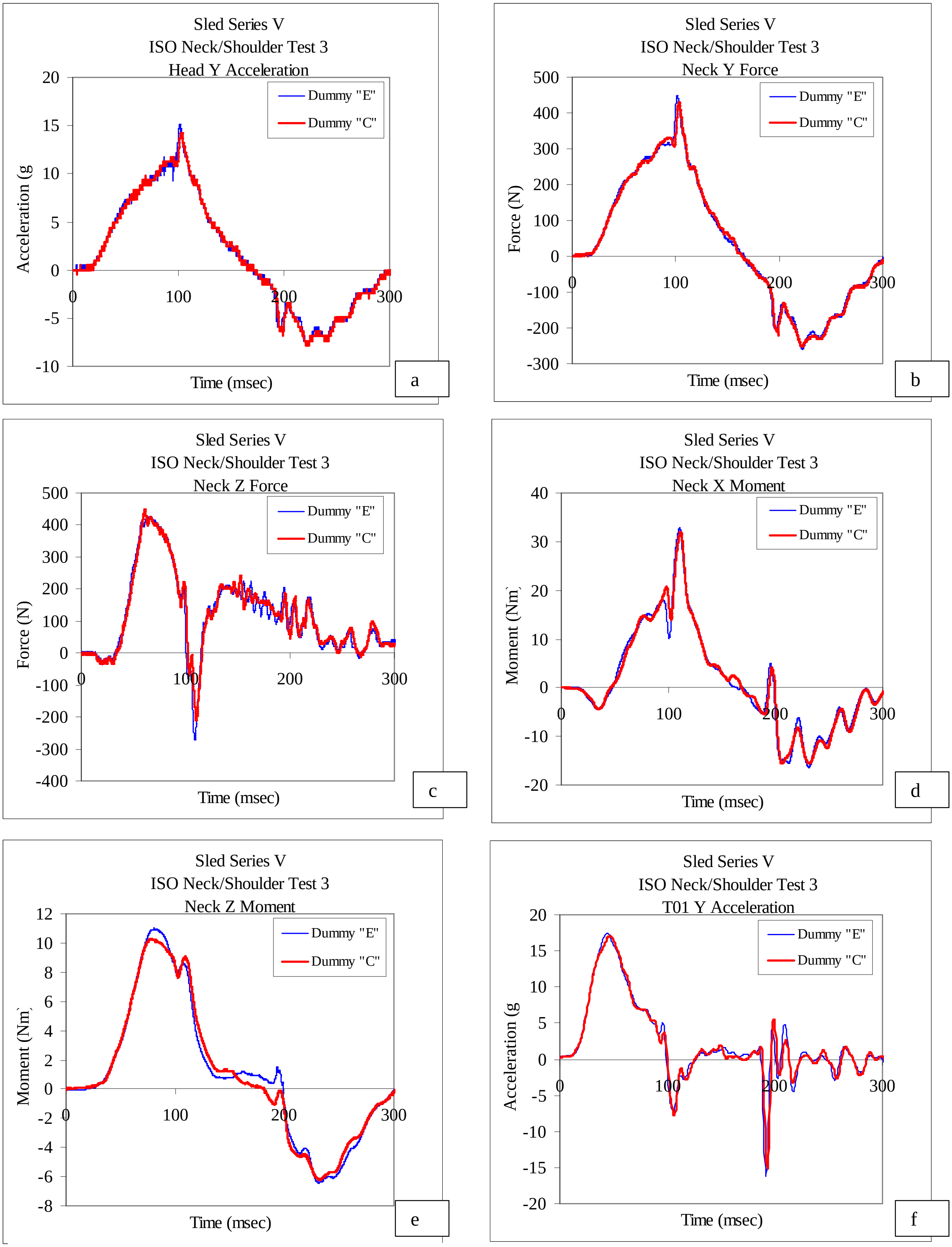
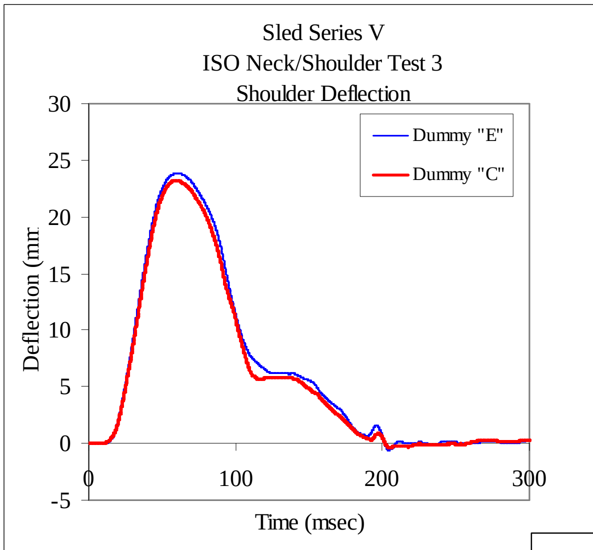


Figure 39. Data traces from ISO Neck/Shoulder Test 3 showing comparison between dummies C and E.



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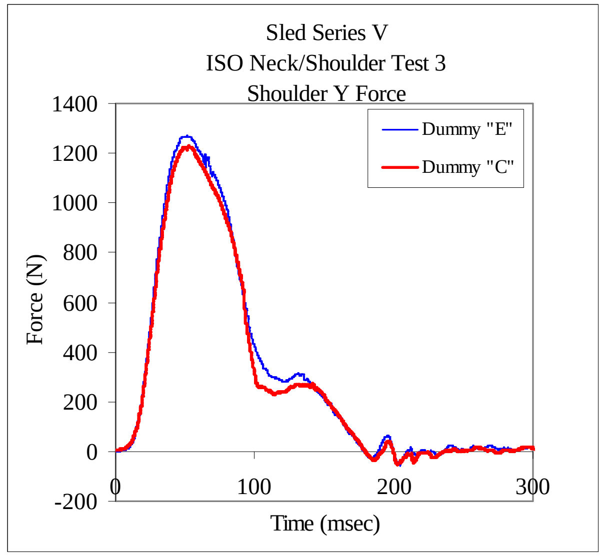

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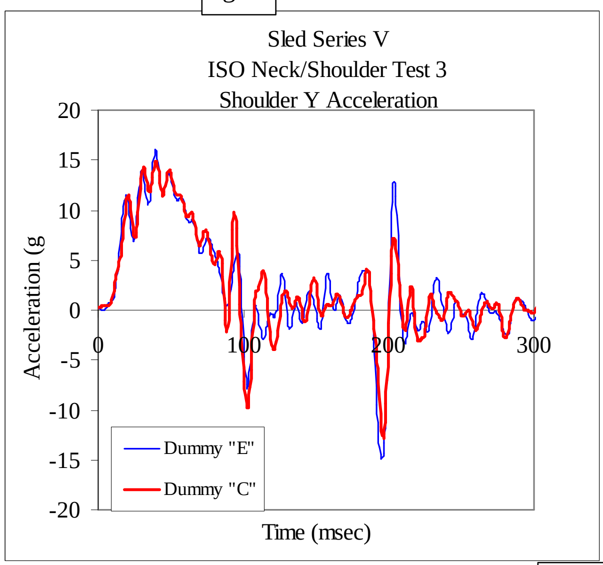

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Figure 39 continued.

Analysis of high-speed video during the three tests showed that similar kinematics occurred, where the arm and shoulder of the dummy slid over the top of the thorax plate, and as the dummy rotated around the abdomen offset, the thorax plate loaded the shoulder vertically. Figure 40 shows comparison data traces from the shoulder region of dummies D and E from the Unaligned, Padded (2” 103kPa) Abdomen Offset tests (Tests 713 and 777, respectively). In the vertical (Z) direction, dummy E experienced comparable amounts of force and acceleration, if not more, than dummy D, indicating that the two dummies’ shoulders were subjected to similar conditions. Since the dummy with the clavicle guide (E) did not sustain any damage from this test, it appears to be superior over the original shoulder guide at restraining vertical motion of the shoulder rib, and causing damage. No damage occurred during Test 778, either, confirming the success of the clavicle guide.

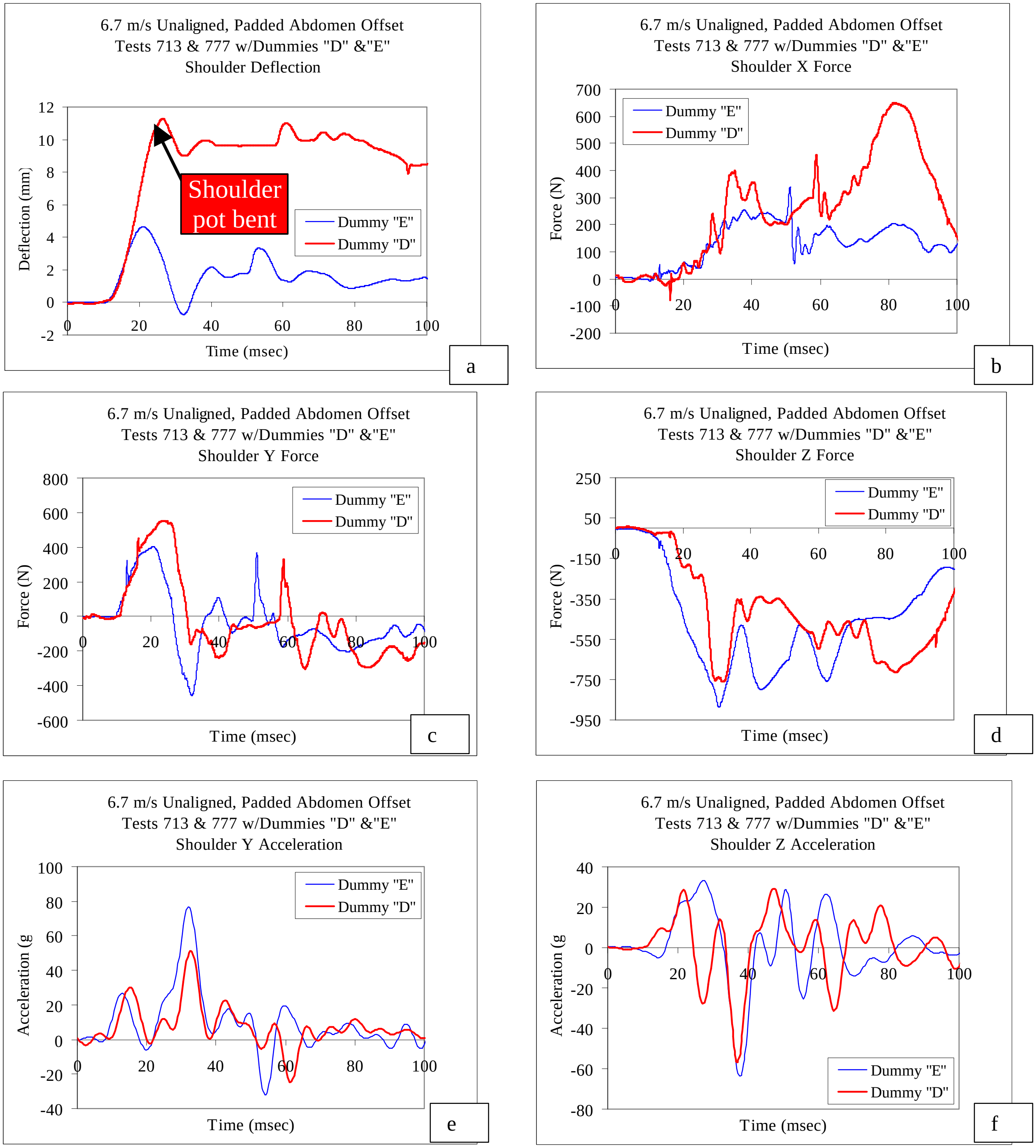


Figure 40. Comparison data traces from the shoulder region of dummies D and E from Tests 713 and 777, respectively, in the Unaligned, Padded Abdomen Offset condition. **Note that in Test 713 the shoulder rib lodged up over the neck bracket, bending the shoulder pot and separating its damping material from the rib steel. No damage occurred in Test 777.**

5.7 Conclusion

Insufficient durability was indicated as consistent damage to the SID-IIs shoulder region occurred. Examination of the mode of shoulder damage yielded a similar mechanism as that of the thorax and abdomen regions: vertical motion of the shoulder rib. VRTC's design of a "clavicle" rod guide that extended beyond the shoulder rib on the impact side appeared to be effective, but the OSRP group felt that the guide invaded the impact area of the dummy and that an intruding structure might interfere with the guide. Based on the viewpoint of the OSRP, FTSS designed a prototype shoulder guide, which VRTC received in June 2002. The FTSS prototype shoulder guide attaches to the dummy using the existing shoulder guide mount holes (Figure 41) and extends farther out toward the front of the shoulder rib than the Original guide. A simple re-shaping of the guide and increase in its depth (as was attempted in the thorax and abdomen regions) was implemented by FTSS. Although it was an obvious non-humanlike feature, there was no opposition from the OSRP group concerning the amount of the guide protruding toward the front of the dummy. Apparently, since the dummy will be used in side impact crash testing, the OSRP felt that the amount of the guide protruding toward the front was not important, as long as the guide did not intrude into the impact region of the dummy (as the VRTC prototype clavicle guide did).

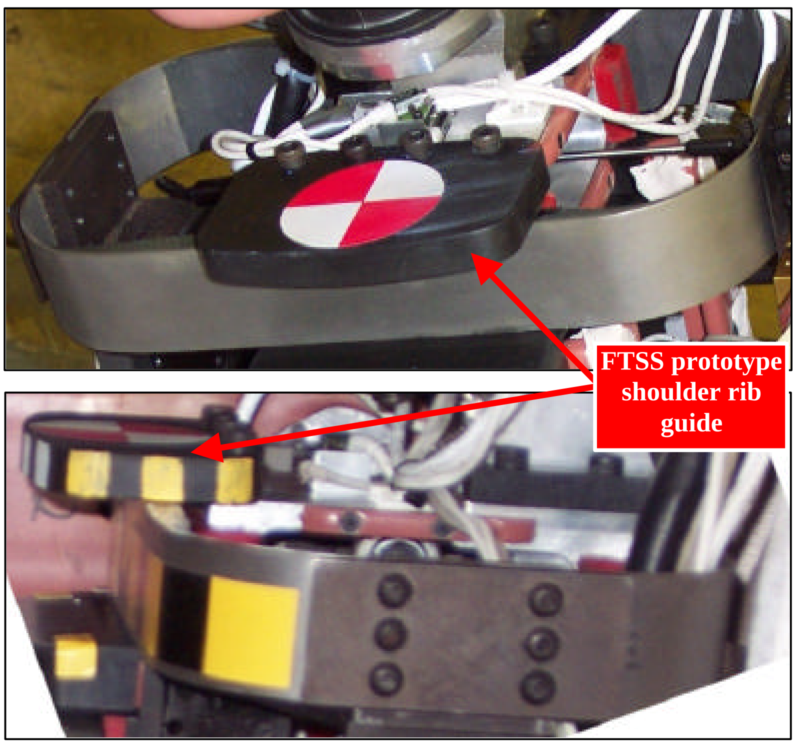


Figure 41. FTSS prototype shoulder rib guide.

As the damping material of the shoulder rib assembly of the original dummy was adhered to the center of the rib steel with roughly ½ inch depth, its attachment was not optimal for preventing it from being sheared off (Figure 42). To improve this condition, FTSS modified the shoulder rib assembly by adhering a thinner piece of damping material along the full width of the rib steel (Figure 43). Further evaluation of the FTSS prototype shoulder and rib guide was performed and is included in Section 7, FTSS FRG Prototype Evaluation.

Figure 42. Shoulder rib assembly of original SID-IIs

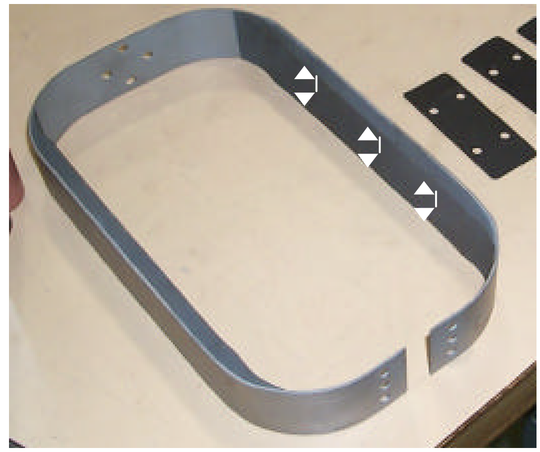


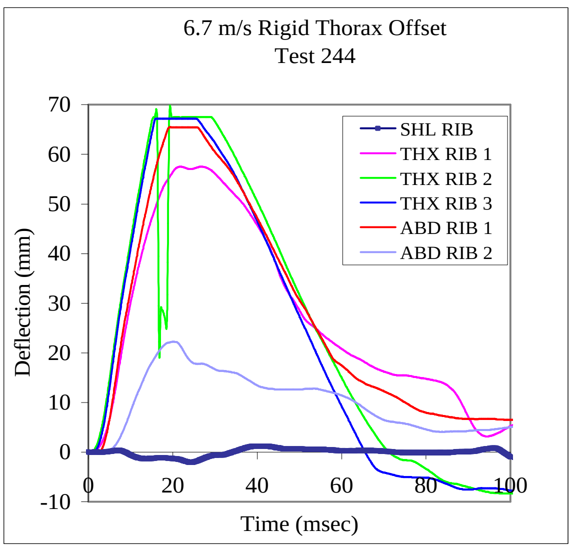
Figure 43. FTSS-modified shoulder rib assembly.

6. Rib Stop Modifications

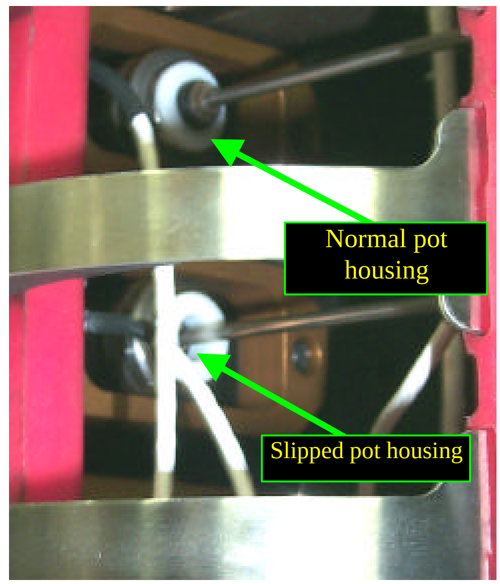
Several instances of damage to the potentiometer shafts and housings occurred throughout the SID-IIs dummy evaluation due to insufficient rib stops. In Figure 2, “Timeline of Critical Events in the Evaluation of the Original SID-IIs,” the column labeled Rib Stops corresponds to this section of the report. The damages observed due to insufficient rib stops are summarized chronologically below.

6.1 Sled Series I

The first indication that the SID-IIs rib stops were inadequate occurred during a Low-Speed Rigid Thorax Offset test of the first sled test series (Table 2) in October 2000. During Test 244, thorax ribs 2 and 3 and abdomen rib 1 reached maximum available deflection (Figure 44a) and the pot housings were pushed into their bearings (Figure 44b).



(a)

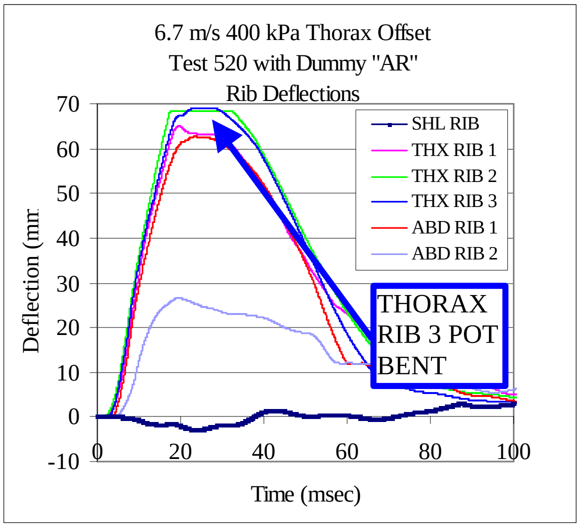


(b)

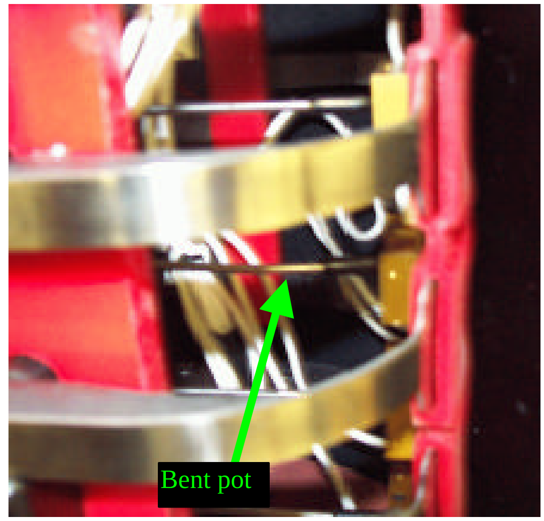
Figure 44. Rib deflection data traces (a) showing “flat-top” for thorax ribs 2 & 3 and abdomen rib 1 due to achievement of maximum available deflection during 6.7m/s Rigid Thorax Offset Test 244 of Sled Series I. Pot housing is pushed into white bushing (b) after Test 244.

6.2 Sled Series II

Then, in Sled Series II (Table 3) in May 2001, during a Low-Speed Padded (400 kPa foam) Thorax Offset (Test 520), thorax ribs 2 and 3 reached maximum deflection (Figure 45a) and the pot shaft of thorax rib 3 bent (Figure 45b). Since the pot reached maximum stroke, it was suspected that insufficient rib stops were the cause of the damage.



(a)



(b)

Figure 45. Rib deflections during Padded Thorax Offset Test 520 (a); Bent thorax rib 3 potentiometer shaft after Test 520 (b).

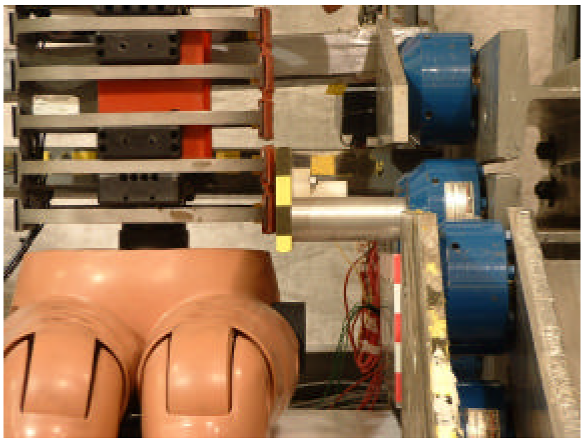
6.3 Sled Series III

In Sled Series III (Table 5) in September 2001, a Low-Speed Rigid Abdomen Offset (Test 644) was performed with the impact wall raised 1 inch in order to align the abdomen offset plate with the abdomen ribs of the dummy (Figure 46a). This aligned plate condition (described in Section 4.5) resulted in abdomen ribs 1 and 2 achieving maximum allowable deflection (Figure 46b), abdomen rib 1 pot bending severely, and the pot housing crushing (Figure 46c). It was quite evident that the rib stops were ineffective and would need modification. Table 14 summarizes the damages observed in the displacement instrumentation.

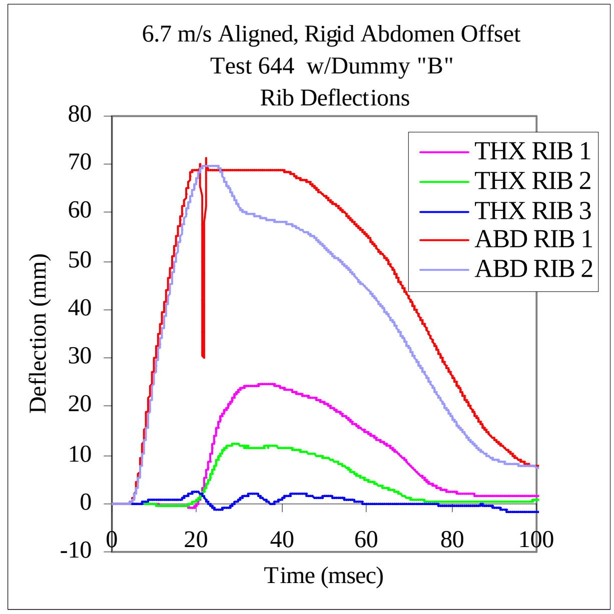
Table 14. Observed Damages Due to Insufficient Rib Stops

Speed & Impact Wall Configuration	Rigid or Padded	Wall Aligned with Abdomen Ribs?	Test #	Test Series/ Table #	Dummy Design	Max. Deflection Achieved?	Damage
6.7 m/s Thorax Offset	Rigid	No	244	I/2	A	Yes	Pot housings pushed into bearings
6.7 m/s Thorax Offset	3" 400 kPa	No	520	II/3	AR	Yes	Thorax rib 3 pot shaft bent
6.7 m/s Abdomen Offset	Rigid	Yes	644	III/5	B	Yes	Abdomen rib 1 pot bent and housing crushed

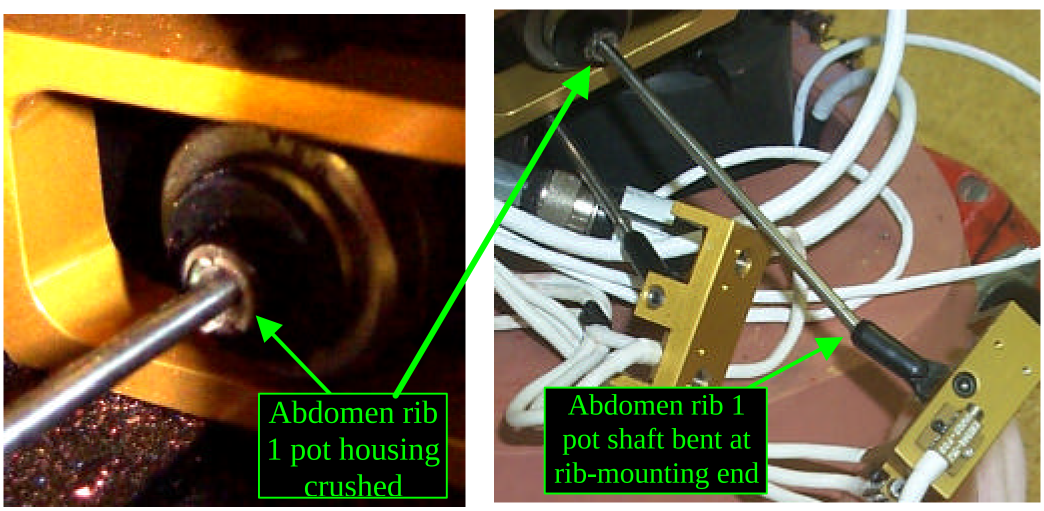
Dummy Design A: original
Dummy Design AR: original dummy, refurbished
Dummy Design B: additional rib guides between thorax rib 3 and abdominal rib 1, in front and rear; 3/8" spacers behind each rib guide; jacket removed



(a)



(b)



(c)

Figure 46. During Aligned Rigid Abdomen Offset Test 644 (a), abdomen ribs 1 and 2 achieved maximum deflection (b), resulting in (c) crushed abdomen rib 1 pot housing and bent abdomen rib 1 pot shaft.

6.4 FTSS Prototype Rib Stops

The consistent damage to the dummy was evidence that the rib stops were not robust enough to protect the instrumentation. FTSS designed new, prototype rib stops that appeared to be an improvement over the original design. Figure 47 shows the original rib stops and Figure 48 shows the new rib stops designed by FTSS. The original rib stops were made of a flexible urethane material that flexed out of the way when contacted by the ribs until the spine box and instrumentation finally stopped the ribs from deflecting. The new FTSS prototype rib stops are made of aluminum with a vinyl coating, a much stronger, robust design.

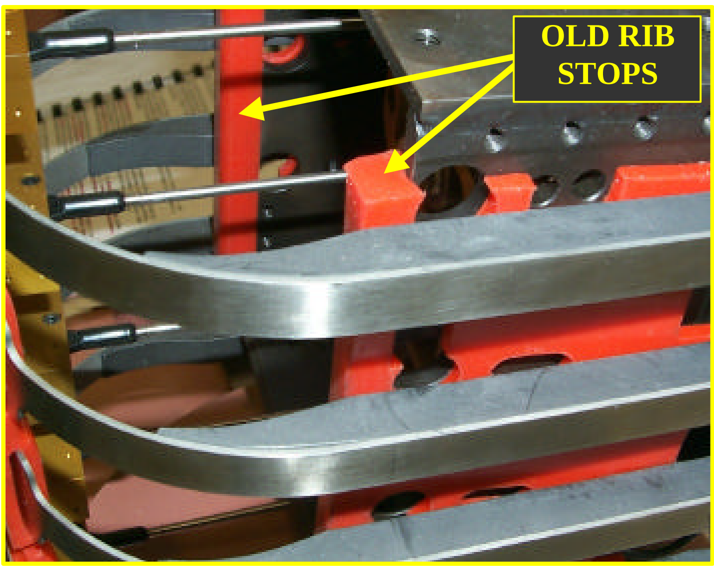


Figure 47. Original rib stops shown in original dummy.

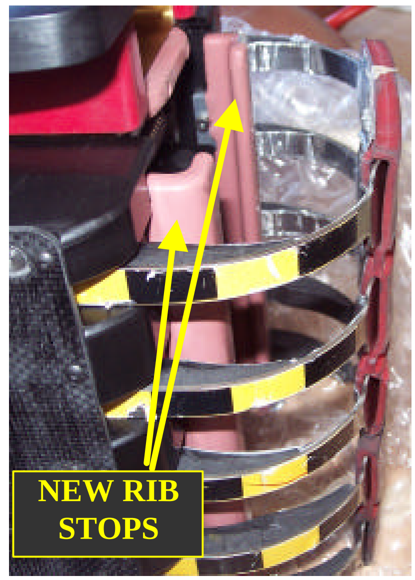


Figure 48. New, prototype rib stops designed by FTSS.

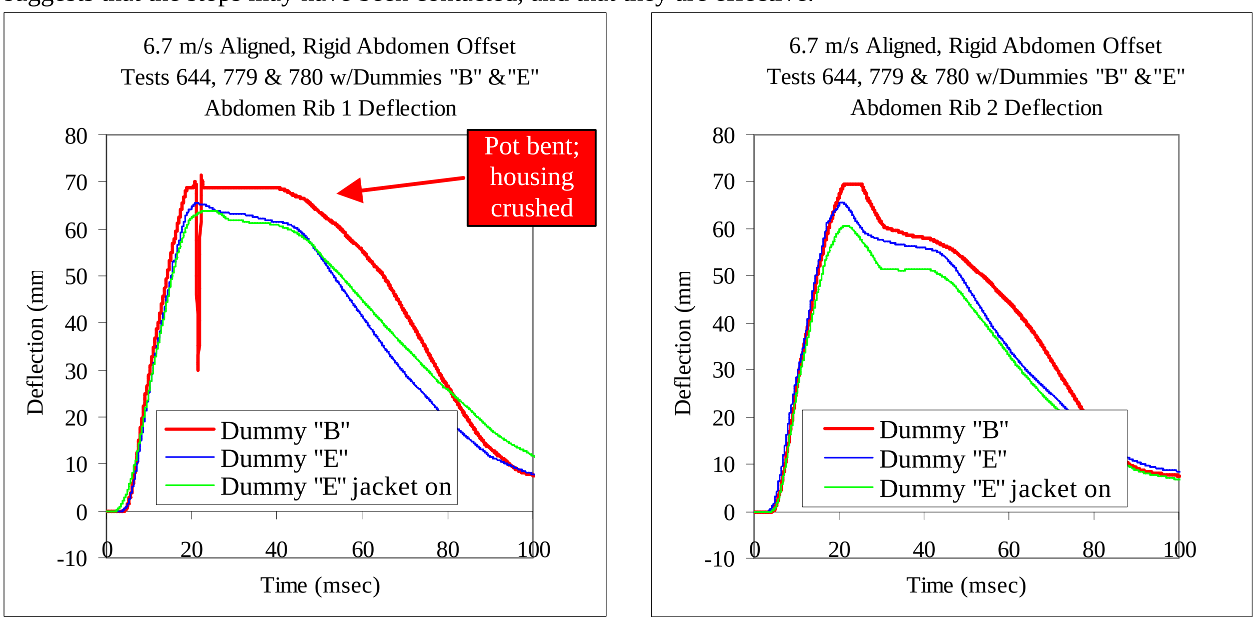
6.5 Sled Series V

Sled Series V was conducted in January 2002 in order to examine the performance of the latest design E with all prototype modifications. The test matrix of Sled Series V (Table 15) included objectives to evaluate each modification type. In order to evaluate the new rib stops, the Aligned condition was implemented in Rigid Thorax and Abdomen Offset tests (highlighted in yellow) since damage was observed in similar conditions during Test 644 (see Table 14). The Aligned Abdomen Offset test was conducted twice with dummy E: once without the jacket on (Test 779), and once with the jacket on (Test 780). The Aligned Thorax Offset test was conducted twice: once with dummy C (Test 784) to observe the effects of the new rib stops, and once with dummy E (Test 781) to observe the effects of the new rib stops along with the FRG and shoulder guide modifications. The Unaligned thorax offset test conditions that resulted in damage (see Table 14) were not conducted as part of Sled Series V, but were conducted at a later time (Sled Series VI). The ISO Neck/Shoulder Tests are discussed in Section 5.6.1 and the Unaligned Abdomen Offset tests of Series V are discussed in Sections 4.10 and 5.6.2.

Table 15. Sled Test Series V Matrix (Rib Stop Modification Evaluation)

Test Conditions	Offset Plate	Test Numbers	Dummy Design / Serial Number
6.7 m/s Padded Abdomen Offset (2” 103 kPa)	Unaligned	777	E / 033
6.7 m/s Rigid Abdomen Offset		778	E / 033
6.7 m/s Rigid Abdomen Offset	Aligned	779	E / 033
		780	E w/jacket on / 033
6.7 m/s Rigid Thorax Offset	Aligned	781	E / 033
		784	C / 033
ISO 9790 Neck Test 3/Shoulder Test 3	n/a	782	E / 033
		783	C / 033
Dummy Design C: additional rib guides between thorax rib 3 and abdominal rib 1, in front and rear; 3/8” spacers behind each rib guide; improved rib stops from FTSS; jacket removed **Dummy Design E:** additional rib guides between thorax ribs 2 & 3, in front and rear; 3/8” spacers behind each rib guide; improved rib stops from FTSS; VRTC prototype FRG; VRTC prototype shoulder guide; jacket removed			

Since one of the test conditions that led to damage in dummy B was the 6.7 m/s Aligned, Rigid Abdomen Offset (Test 644), this test condition was repeated with dummy E, having the latest prototype modifications (Test 779 without jacket, and Test 780 with jacket) to observe the effects of the prototype parts, especially the new rib stops. Figure 49 shows the abdomen rib deflection data traces for the three tests. Figure 49(a) shows that abdomen rib 1 did not flat-top in Tests 779 and 780 as it did in Test 644. The flat-top and potentiometer damage suggest insufficient rib stops with dummy B. Since no damage and no flat-top occurred with dummy E in Tests 779 and 780, it is not clear whether or not the ribs contacted the new rib stops; however, the plateau in the abdomen rib 1 data traces suggests that the stops may have been contacted, and that they are effective.



(a) (b)

Figure 49. Abdomen rib 1 (a) and abdomen rib 2 (b) deflection data traces from Tests 644, 779 and 780 with dummies B and E showing effect of prototypes, including FRG, shoulder “clavicle”, and new rib stops. Note that no damage occurred with dummy E in Tests 779 and 780.

To further evaluate the new rib stops, two Aligned, Rigid Thorax Offset tests were conducted with dummies C and E (Tests 784 and 781, respectively). No damage occurred to the instrumentation during these tests, and the new, prototype rib stops appeared to be effective.

6.6 Summary of Rib Stop Modifications

Consistent damage to the SID-IIs instrumentation revealed durability problems due to insufficient rib stops. The Original flexible urethane stops were replaced with vinyl-coated aluminum stops by FTSS. The new rib stops appeared to be effective during Sled Series V. The OSRP group agreed to change the design and at the OSRP meeting in February 2002, the committee agreed that the thoracic, abdominal, and shoulder ribs would have maximum deflection in the 60-63mm range before coming into contact with the new rib stops. This would allow for a maximum potentiometer measurement of approximately 65-66mm, since the ribs can still bend a little once the rib stops are impacted, causing a small amount of further deflection to be measured. The maximum rib deflection range was reduced from 69mm in order to further protect the potentiometers, while still allowing deflections well above any injury criteria (current non-NHTSA proposed criteria in the 35-40mm range) to be measured.

7. FTSS FRG Prototype Evaluation

Prior to the FRG design, the Original SID-IIs dummy was found to exhibit durability issues including damaged ribs, bent potentiometer shafts, and crushed potentiometer housings (Sections 4 –6 of this report). Examination of the causes of the damage revealed that vertical forces on the ribs, as during an offset-wall sled test, caused the ribs to expand outside of the rib guides and "jump" upwards beyond the guides. Damages to the potentiometers and ribs resulted. Therefore, much of the evaluative process of the FTSS FRG prototype was dedicated to assuring that the FTSS FRG resolved these durability issues. This section of the report summarizes both the evaluation of the FTSS FRG prototype dummy and design progression resulting from testing. In addition, discussion of comparison tests between the Original SID-IIs and FRG dummies is included. In Figure 2, "Timeline of Critical Events in the Evaluation of the Original SID-IIs," all events between June 2002 and June 2003 correspond to this section of the report.

Figure 50 illustrates the FTSS FRG prototype as it was received from FTSS in June 2002. For simplicity, the FTSS prototype design of the SID-IIs dummy is referred to as the FRG dummy even though it includes shoulder rib and guide and rib stop modifications in addition to the Floating Rib Guide design. The FTSS FRG dummy included the same rigid rib stops as in design E; however, the FTSS FRG dummy included the new shoulder rib with narrower damping material that spanned the full width of the rib and a new shoulder rib guide from FTSS rather than the clavicle guide by VRTC. FTSS made several changes to the Floating Rib Guide design, which differed from VRTC's design, denoted by orange boxes in Figure 50. The FTSS FRG design included two major differences from the VRTC design: a flexible urethane cover plate (as opposed to a stiff Teflon plate); and two spring pins per guide at guides 2 and 4 with two guide pins per guide at guides 1, 3, and 5 (VRTC design had four spring pins per guide at guides 2, 3, and 4, and guides 1 and 5 were simply attached to the cover plate).

The evaluation of the FTSS FRG prototype began in July 2002. During the evaluation process of the FTSS FRG prototype, several more design modifications were necessary. The flowchart in Figure 51 summarizes the FTSS FRG evaluative process and resulting design changes.

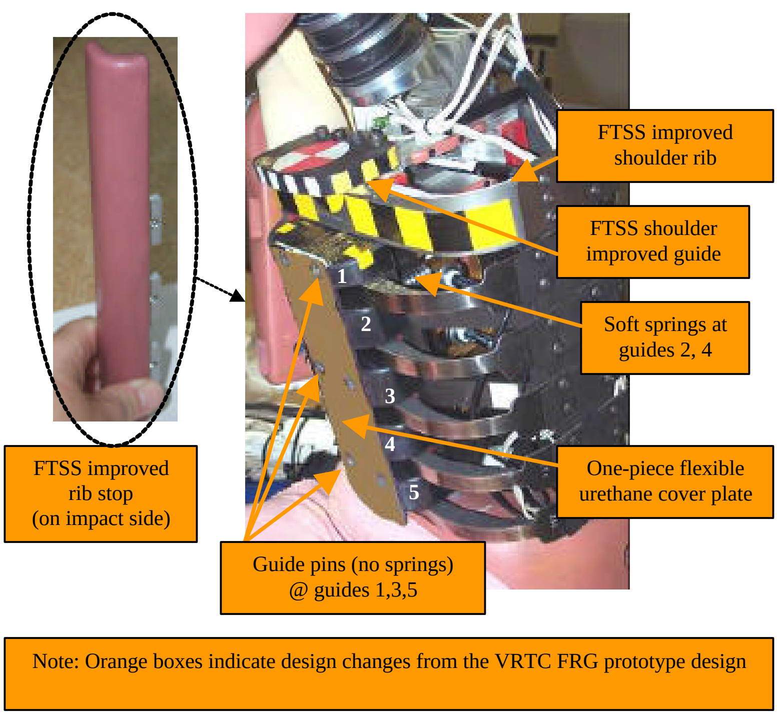


Figure 50. FTSS Prototype FRG Dummy as received from FTSS in June 2002

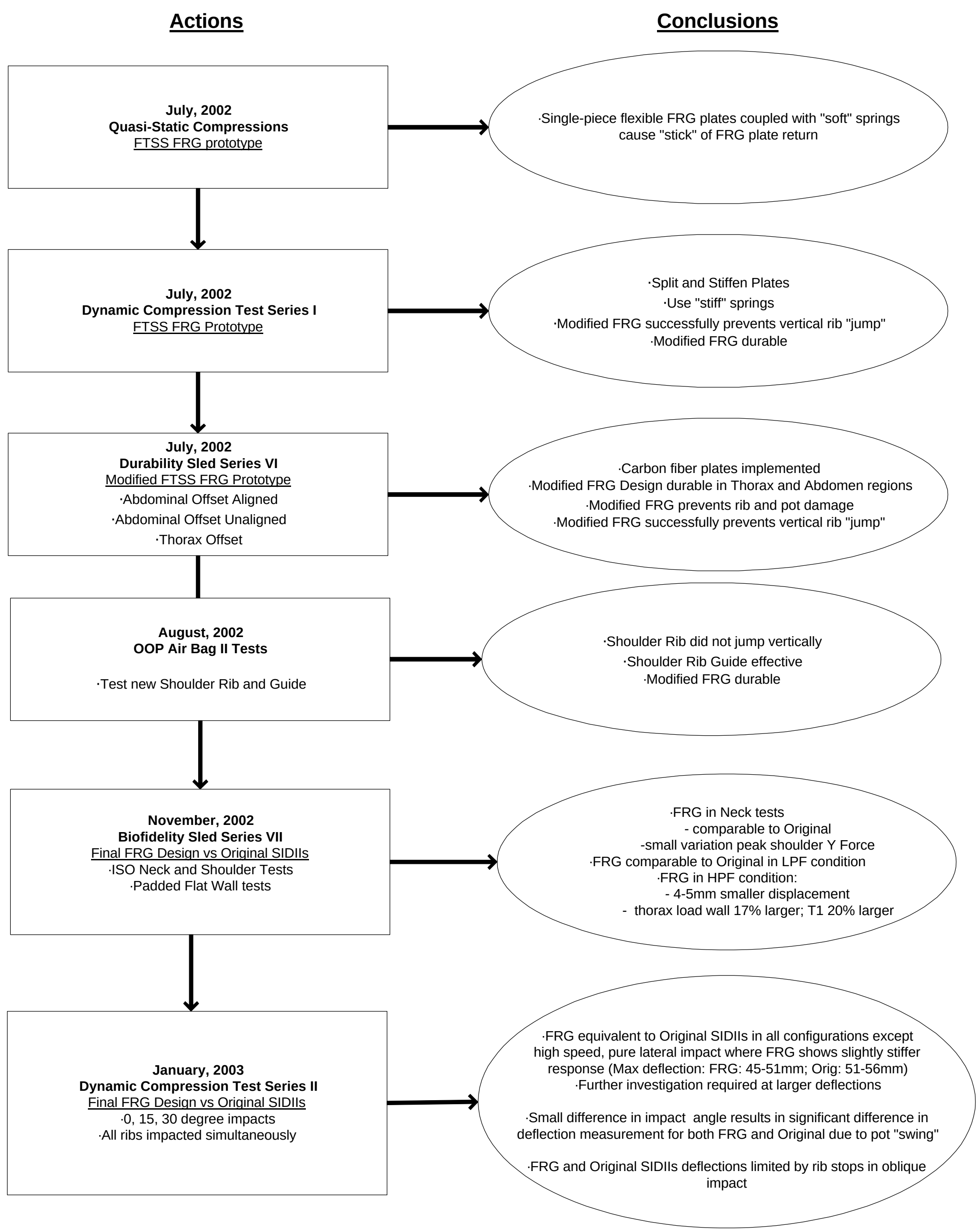
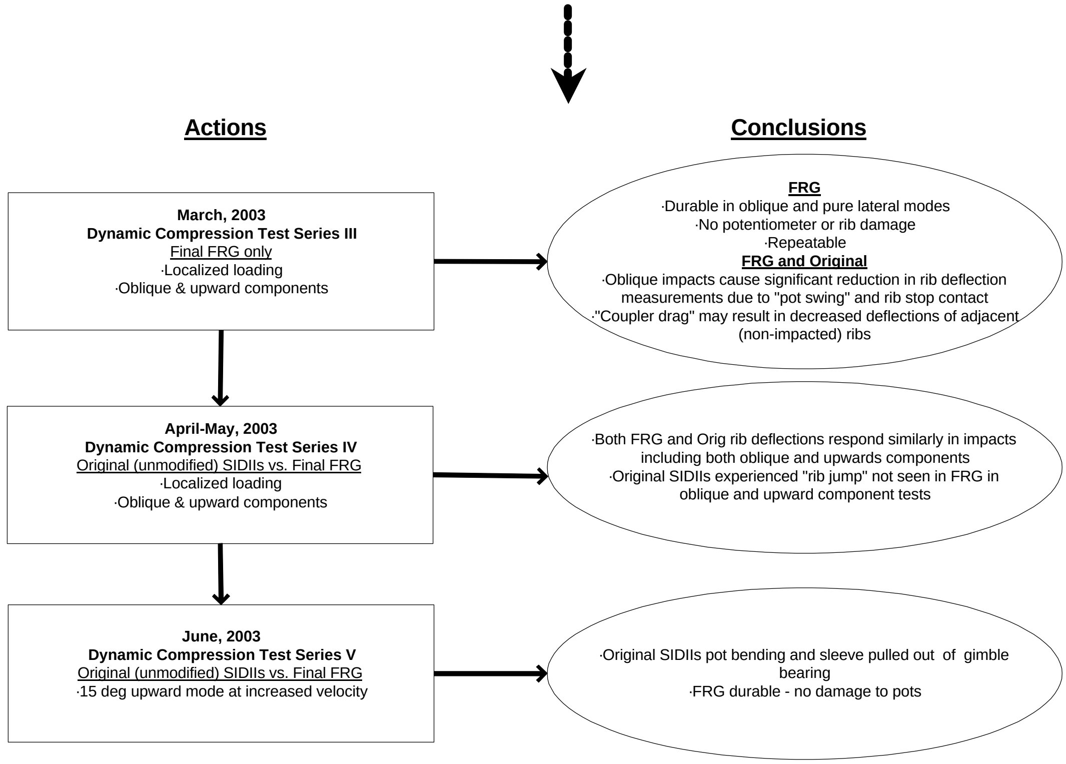


Figure 51. Flowchart of evaluation testing and outcome of the FTSS SID-IIs FRG

(Figure 51 continued from previous page)



7.1 Quasi-static Compression Tests (July 2002)

In July 2002, ten quasi-static torso compression tests were performed to examine the functionality of the FRG design during compression. Two repeat tests were performed for each test configuration. The thorax of the FRG was positioned under a quasi-static test machine such that the various rib regions could be compressed. Figure 52 shows the test setup for compression of the abdominal ribs. Compressions were also performed on the thoracic ribs, shoulder rib, and all ribs (except the shoulder) simultaneously (Table 16). The compressions were conducted at a rate of 305 mm/min (12”/min) up to 50.8 mm (2”) of compression-head displacement.

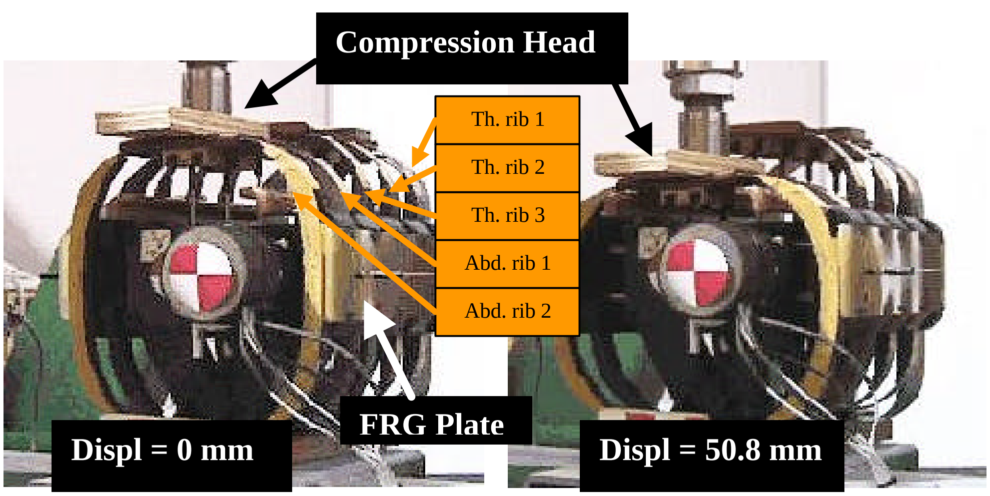


Figure 52. Quasi-static abdomen compression test setup for the FRG prototype (bottom view)

Table 16. Matrix of Quasi-static Compression Tests with the FTSS FRG Prototype

	Thoracic Ribs	Abdominal Ribs	Shoulder Rib
Compression Location	X		
		X	
			X
	X	X	

During the abdominal displacement tests, it was noted that the (lower) floating rib guides did not return to their initial position after the deflection event. Figure 53 shows a close-up side view of the FRG thorax during a quasi-static compression test. After the end of the outward rib movement, the guides appeared to "stick", not returning the FRG cover plates and rib guides to their initial positions. Flexible, one-piece FRG plates in the front and rear, coupled with return springs that were too soft to effectively return the plates, were likely the cause of this event. These items were noted and addressed in more detail in the dynamic impact tests (see Section 7.2).

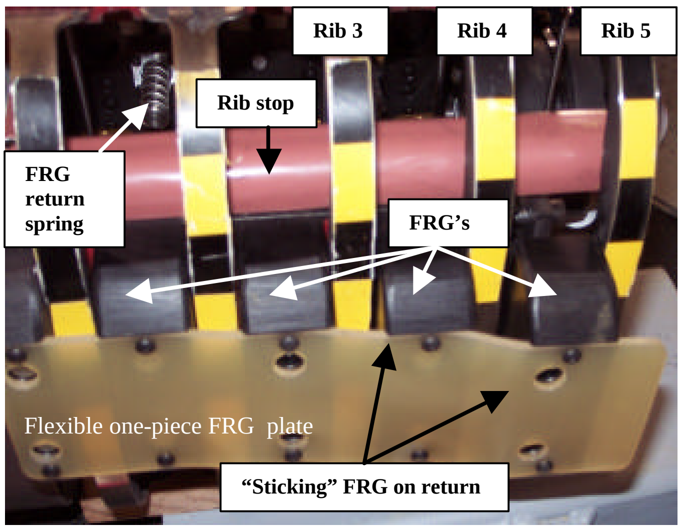


Figure 53. Flexible one-piece FRG plate binding on rib return during quasi-static tests

The conclusions for the quasi-static compression test series are summarized in Figure 54. These tests indicated that the single-piece FRG plates, coupled with soft springs, caused "stick" during the FRG plate return. These findings prompted the initiation of dynamic compression tests (Section 7.2) to examine these issues in a dynamic environment.

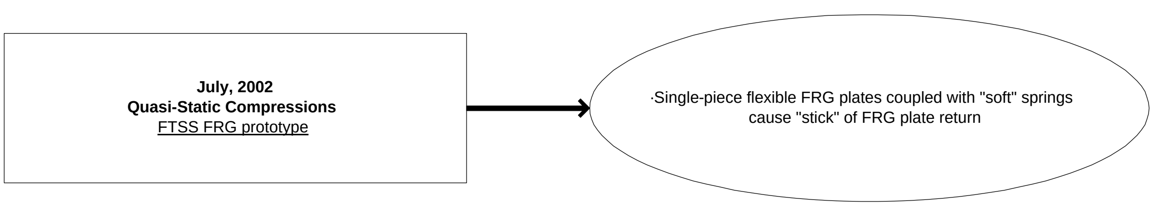


Figure 54. Summary of July 2002 quasi-static compression tests

7.2 Dynamic Compression Test Series I (July 2002)

Immediately following the quasi-static compression tests in July 2002, dynamic impact compression tests were conducted. These tests were performed in order to assess the performance of the FRG design in a dynamic environment and to further examine the FRG plate return issues discussed in the previous section. Assessments included durability, repeatability, and successful prevention of vertical rib motion and damage of the dummy in a controlled dynamic environment.

For these tests, the FRG thorax was mounted in a rigid, braced, fixture (so that the spine box did not translate) and impacted with a freely moving, linearly guided impactor (32.7 kg) at various velocities between 2 – 6 mph (Figure 55). Four different impact modes were examined (Table 17). The impact was either directed laterally straight into the ribs (0º) (Figure 55) or laterally with a 20º upwards component (Figure 56). Impact combinations of various ribs were examined to simulate localized loading conditions. For example, impacts were directed into the abdominal ribs only (Ribs 4 and 5), the thoracic ribs only (Ribs 1, 2, and 3) or a combination of abdominal and thoracic ribs (Ribs 3, 4, and 5). Twenty-six (26) tests were conducted. The impact faces for this series were simple blocks of wood cut to the appropriate size to contact the ribs of interest (either 2 or 3 ribs).

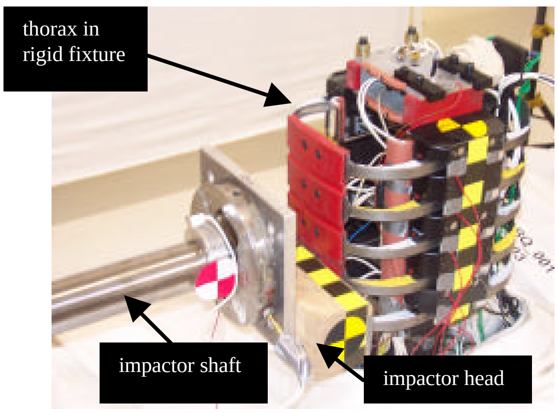


Figure 55. Example of dynamic compression test setup used throughout FRG prototype evaluation testing

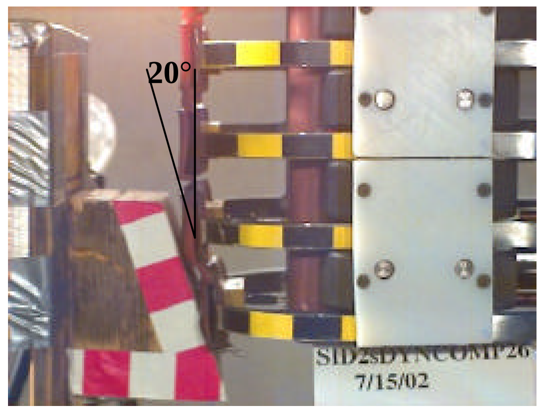


Figure 56. Setup for 20º upward impact in Dynamic Compression Test Series 1

Table 17. Test matrix summary for Dynamic Compression Test Series I (July, 2002)

Impact Location	Vertical Impact Direction	Number of Impacts
Abdominal Ribs Only (ribs 4 & 5)	0º (straight)	12
	20º upwards	3
Lower Thoracic Rib + Abdominal Ribs (ribs 3, 4, & 5)	0º (straight)	6
Thoracic Ribs Only (ribs 1, 2, & 3)	0º (straight)	5

This test series served as a mode for optimizing the FRG design by allowing immediate changes to the design to be examined in a controlled dynamic configuration. Figure 57 shows a flowchart of the progression of FRG design changes implemented during this test series. Since in this stage most design refinements were directed towards the FRG plates, the photos in Figure 57 show the progression of FRG plate changes within this series. Table 18 summarizes these changes and explains why they were necessary.

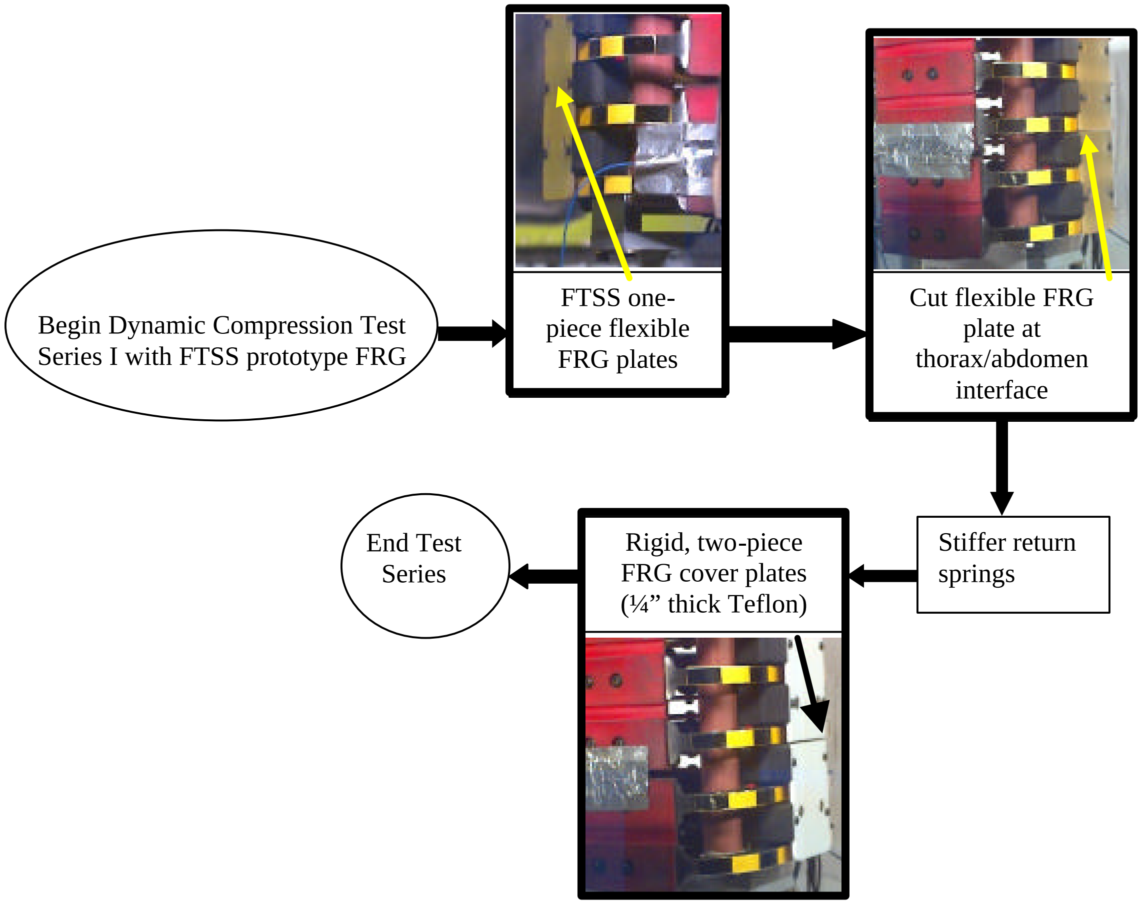


Figure 57. Test progression flowchart for Dynamic Compression Series I

Table 18. Changes made to the FTSS FRG as a result of Dynamic Compression Test Series I

Pre-Test FRG Configuration	Post-Test FRG Configuration	Reason for Change
flexible sternum and spine FRG plates	stiff ¼" thick Teflon sternum and spine FRG plates	compliant plate resulted in binding of floating rib guides
One-piece sternum and spine FRG plates	two-piece sternum and spine FRG plates split at thorax/abdomen interface	mimic Original SID-IIs rib coupling to optimize plate return
"soft" FRG rib return springs	"stiff" FRG rib return springs	FRG plate return too slow

Figure 58 summarizes the conclusions for Dynamic Compression Test Series I. Design changes prompted by these tests included rigid plates divided at the thorax/abdomen interface, and stiffer springs to assure proper plate return. In addition to these design changes, the FRG proved durable in a dynamic environment and illustrated the ability of the FRG to successfully eliminate "rib jump".

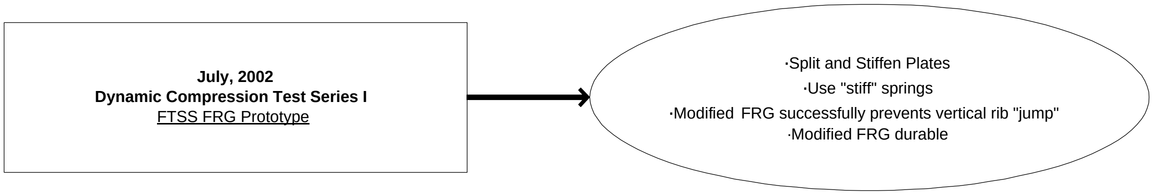


Figure 58. Summary of Dynamic Compression Test Series I

7.3 Durability Sled Test Series VI (July, 2002)

In July 2002, a durability sled test series of seven tests (Series VI) was conducted with the modified FTSS Prototype FRG (rigid, two–piece cover plates and stiff springs). The most severe side impact configurations were selected (rigid thorax and abdomen offsets) in order to address durability (Figure 59). These test configurations were previously conducted with the Original SID-IIs (Section 4.1), which resulted in damage to the dummy (Table 19). Table 19 also includes FRG durability response for this sled series. For the first test in the sled series, the ¼" thick two-piece Teflon cover plates tested in Dynamic Compression Test Series I (Section 7.2, Figure 57) were utilized. For subsequent tests, the FTSS-designed, $^{1}/_{8}$" thick carbon fiber, two-piece cover plates were tested (Figure 60). The thicker Teflon plates were a quick intermediate solution until the stiffer and thinner carbon fiber plates were received from FTSS. During Sled Test Series VI, the latest FRG did not experience potentiometer or rib damage as seen in the Original SID-IIs dummy. Figure 61a illustrates the final design configuration of the SID-IIs dummy as a result of the VRTC evaluation.

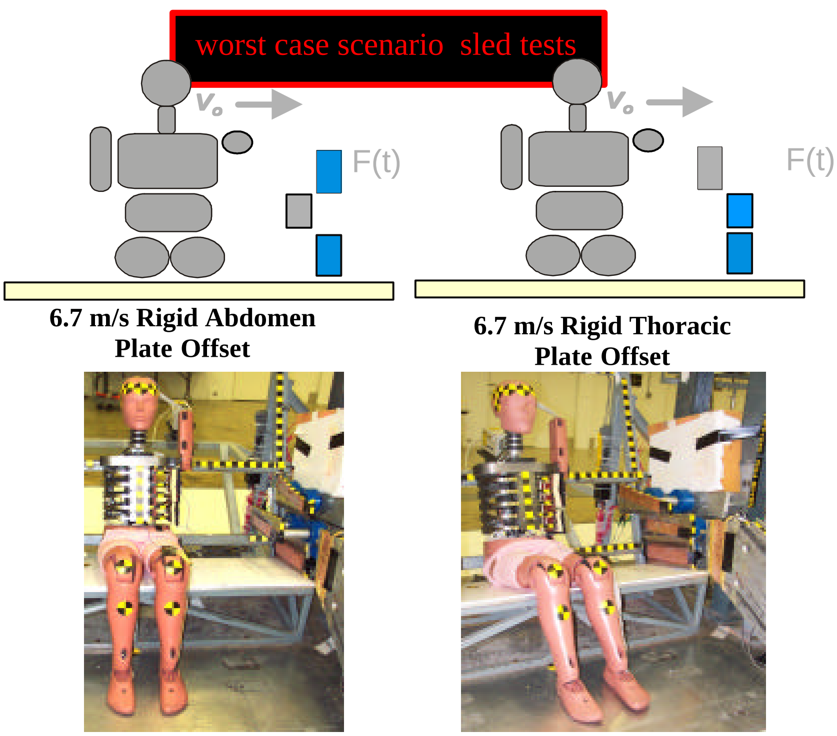


Figure 59. Setup for FRG Durability Sled Series VI

Table 19. Durability Sled Series VI (July 2002) Test Matrix and Durability Results

Test #	Test Condition	Offset Load Wall Aligned with Corresponding Dummy Region?	FRG SID-IIs Performance in this Sled Series	Past damages To Original SID-IIs**
975* 976 979 980	**6.7 m/s Rigid Abdomen Offset**	No	• No damage to pots • No deformation of ribs	• Pot housing crushed • Pot shaft bent • Gouges in damping material • Ribs deformed
977 978	**6.7 m/s Rigid Thorax Offset**	No	• No damage to pots • No deformation of ribs	• Gouges in damping material • Pot shaft bent • Ribs deformed
981	**6.7 m/s Rigid Abdomen Offset**	No	• No damage to pots • No deformation of ribs	• Pot housing crushed • Pot shaft bent • Gouges in damping material • Ribs deformed

* utilized ¼" thick two-piece Teflon cover plates; subsequent tests used FTSS carbon fiber cover plates
** see Tables 7b and 14

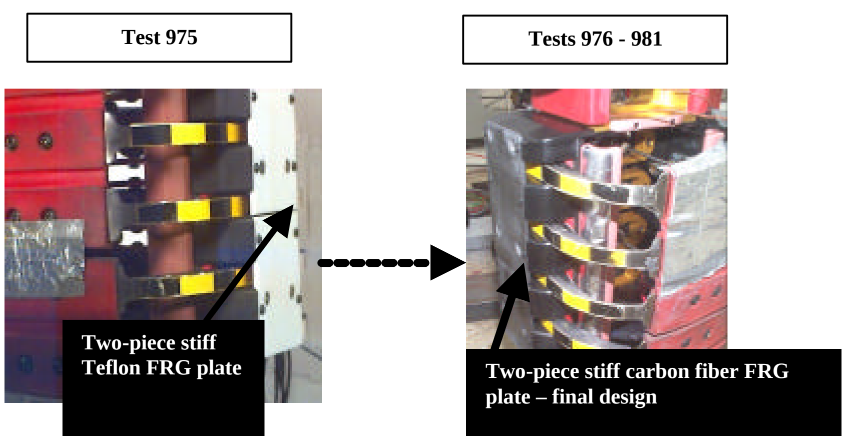


Figure 60. FRG plate design change that occurred during Sled Test Series VI

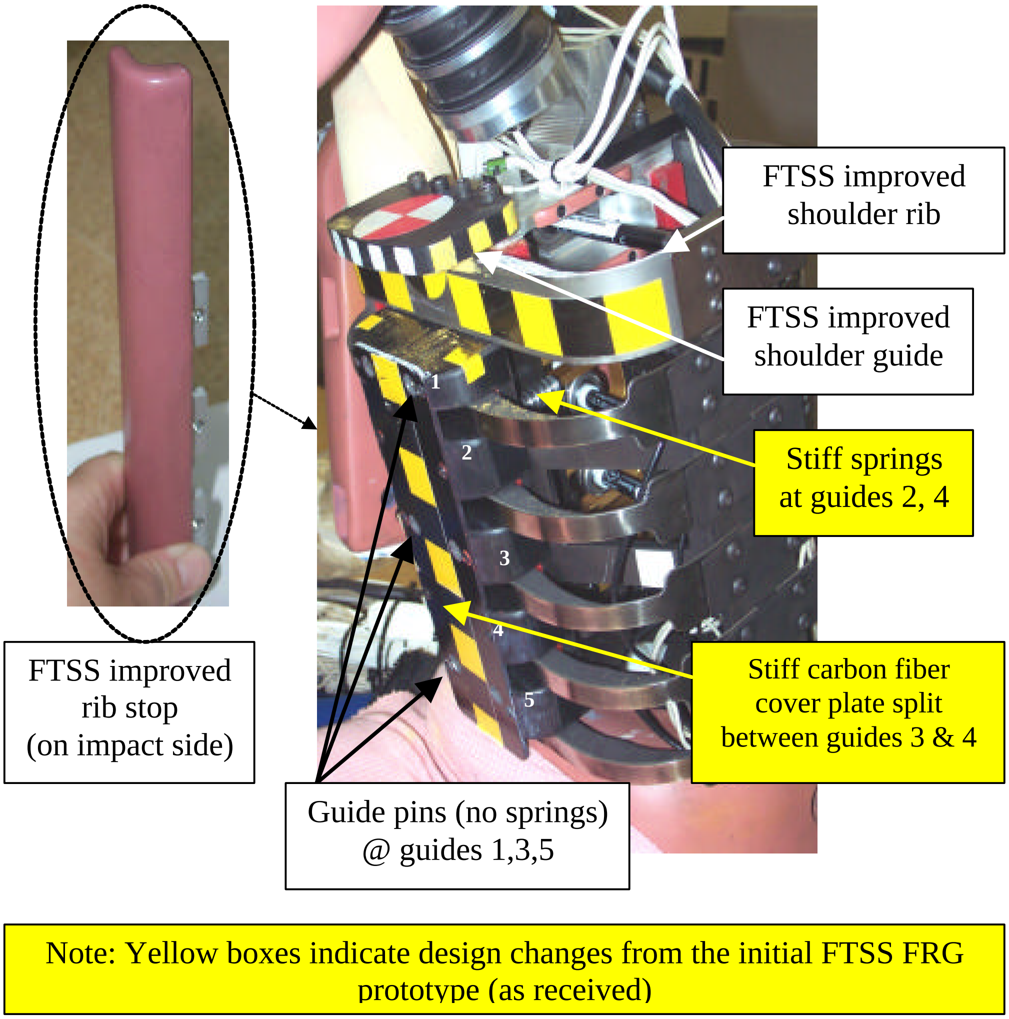


Figure 61a. Modified FTSS FRG Dummy in final configuration after VRTC testing

As the VRTC evaluation of the SID-IIs occurred, OSRP adopted a design change, which included attaching the thorax and abdomen foam pads directly to the ribs via Velcro straps, as opposed to housing them in pockets of the jacket. This change was made to address repeatability issues observed during certification tests due to the ability of the pads to move within the jacket pockets during testing. Test Series VI began with the velcroed pads. However, during Series VI it was noticed that the top of the abdomen pad became caught between thorax rib 3 and abdomen rib 1. To alleviate this problem, VRTC removed ¼” from the top of the abdominal pad. In addition, the tightness of the Velcro attachment was not specified, which allowed for variability, so cable ties were substituted for the Velcro straps. VRTC analyzed the effect of the tightness of attachment on repeatability using Velcro, cable ties and various numbers of attachment points during certification tests. Results indicated that the cable tie method yielded slightly more repeatable results since the Velcro was difficult to attach, which made achieving a tight fit around the pads difficult. Thus, VRTC incorporated cable tie attachments for the thorax and abdomen pads and removed the pockets from the jacket. Figure 61b illustrates the new pad attachment.

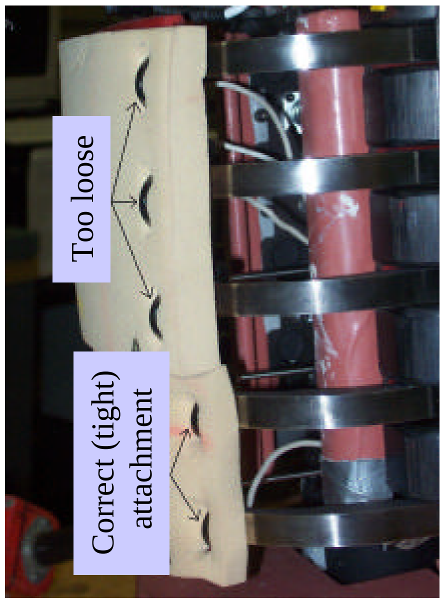


Figure 61b. VRTC’s new thorax and abdomen pad attachment method using cable ties. Note that abdomen pad in this figure does not reflect the ¼” cut from the top of the abdomen pad.

Figure 62 below summarizes Durability Sled Test Series VI. This test series successfully exercised both the thoracic and abdominal rib regions. Results indicated that the latest FRG was not only durable, but effectively prevented rib “jump” and potentiometer damage issues which were evident in the Original SID-IIs design.

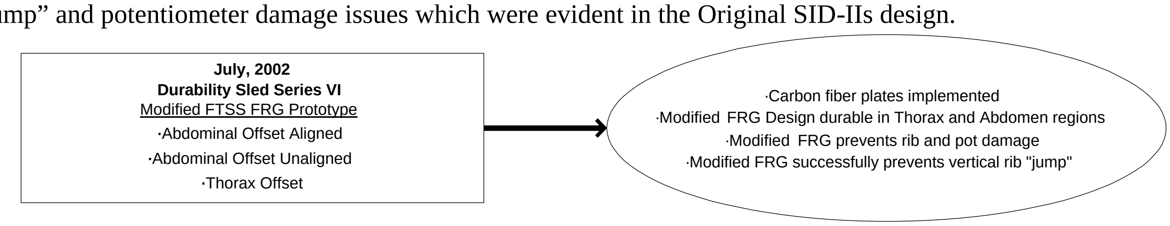


Figure 62. Durability Sled Series VI flowchart summary

7.4 OOP Airbag II (August 2002)

Previous sled test scenarios had sufficiently tested the durability of the thoracic and abdominal ribs; however, the configurations chosen did not effectively examine the durability of the revised shoulder rib (which contained a wider rib damping material area), and redesigned (front) shoulder rib guide (see Figure 41 and Figure 43). An out-of position (OOP) side air bag test was selected because Test F01_218 in OOP Airbag I (Section 5.2) with the unmodified SID-IIs resulted in damage to both the shoulder rib and shoulder pot in this test situation (see Table 9). In August 2002, two similar OOP tests were conducted with the FTSS FRG SID-IIs.

The tests were conducted in the passenger side of a 2000 BMW 528i, as before. For both tests, the dummy was positioned directly against the side air bag; for the second test, the dummy was repositioned further rearward for more complete contact with the side air bag (Figures 63 and 64). These configurations allowed the side air bag to contact the thoracic and abdominal ribs with an upward component.

Figure 63. FRG SID-IIs OOP Test 1

Figure 64. FRG SID-IIs OOP Test 2 (Note dummy is moved rearward)

In the unmodified SID-IIs design, excessive damage to the shoulder rib and shoulder potentiometer occurred during this test configuration. The FRG design with modified shoulder rib and guide utilized in these tests successfully eliminated this kind of damage. The shoulder rib guide design appeared to contain the rib from "jumping" out and causing damage to the pot and the rib. Figure 65 indicates the contact evidence of the shoulder rib under the surface of the shoulder rib guide (note areas where chalk has been rubbed off by the rib).

Figure 65. Shoulder guide after the OOP test

The flowchart element below (Figure 66) summarizes the OOP tests performed. Test results indicated that the shoulder rib design and accompanying (front) shoulder rib guide were effective in this extreme environment and that the FRG proved durable.

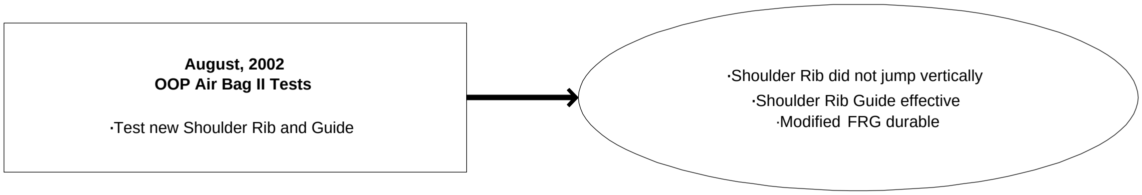


Figure 66. OOP Airbag II summary

7.5 Biofidelity Sled Test Series VII (November 2002)

Eight sled tests were conducted in November 2002 to examine the biofidelity of the final FRG dummy (see Figure 61), as well as to compare to the Original (unmodified) SID-IIs in a dynamic, full-body test environment. Sled tests were performed with both the Original (unmodified) SID-IIs and the final FRG SID-IIs dummies. First, ISO (ISO, 1999) neck/shoulder tests were conducted for biofidelity examination. For these tests, the dummy thorax was restrained to allow only neck and shoulder motion (Figure 67). In addition, low speed (6.7 m/s) and high speed (8.9 m/s), padded, flat, wall tests were performed (Figure 68) with both dummies. The same side impact test buck described in previous test series (I – VI) was utilized. The test matrix for these tests is presented in Table 20.

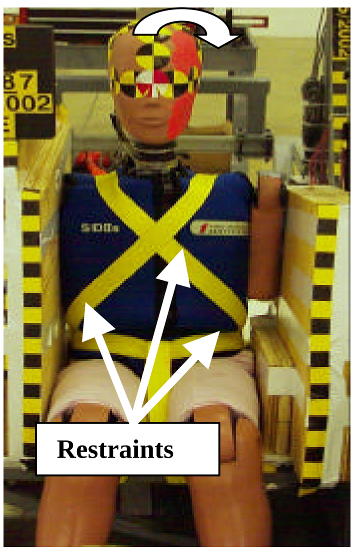


Figure 67. Biofidelity neck test setup

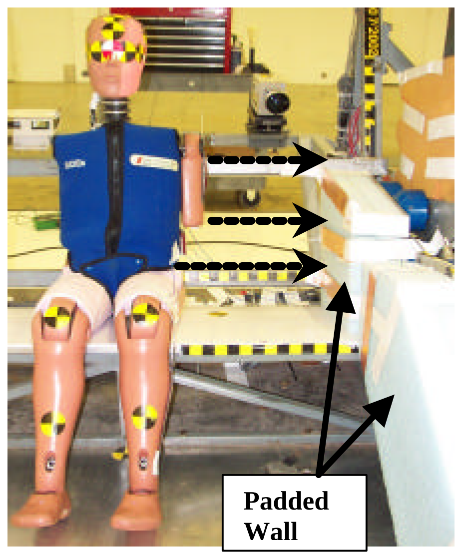


Figure 68. Flat, padded wall test setup

Table 20. Biofidelity Sled Test Series VII Matrix (November 2002)

Test Date/Test Number	Test Type	Dummy
021105-1	Neck Test 1 /Shoulder Test 2	Original #56
021106-2		FRG #33
021105-2	Neck Test 3 /Shoulder Test 3	Original #56
021106-3		FRG #33
021107-1	6.7 m/s Padded* Flat Wall Impact	FRG #33
021111-1		Original #56
021107-2	8.9 m/s Padded* Flat Wall Impact	FRG #33
021111-2		Original #56
FRG in this series is final design		

*4 $^{3}/_{8}$ inches 103kPa foam

7.5.1 ISO Neck/Shoulder Test Results

The results from ISO Neck Test 1/Shoulder Test 2 are presented in Table 21. Shaded areas indicate measurements out of the scaled biomedical targets. Red boxes indicate measurements made via high-speed video and red text indicates dummy responses that are somewhat different between the Original and FRG. In all but the case of the peak vertical head acceleration and peak head flexion angle (for which the FRG fell slightly below the specification), both the Original and the FRG SID-IIs dummies passed or failed the same criteria. Results for peak horizontal and vertical displacement of the head cg with respect to T-1 suggest that the FRG dummy's response is lower than that of the Original by roughly 10 mm; however, the FRG design contains no changes to the head or neck from which these measurements were taken. Thus, these measurement differences must be due to some other factor of variability (note that repeatability and reproducibility of the SID-IIs dummy has not yet been assessed). The peak head flexion angle measurement for the FRG is also lower than the Original (by 10°). This measurement takes into account movement of the head, neck, and torso, so it is possible that this response is lower due to the FRG; however, given that the head cg displacements relative to T-1 are also lower with the FRG and are *not* due to the modifications, it is likely that the head flexion response is also not due to the modifications. It is worth noting that these measurements were made via high-speed video analysis (denoted by red boxes), which may not be as accurate as direct measured responses.

Table 21. ISO Neck Test 1/Shoulder Test 2 Results From Sled Series VII

ISO Neck Test 1/Shoulder Test 2 (7.2 G)		Serial Number 56 Original	Serial Number 33 FRG
	Spec Bounds	**S021105-1**	**S021106-2**
Peak Horiz Accel T1 (G)	**10 –15**	12	11
Peak Horiz Disp Non -Rotating T1 relative to sled (mm)	**38 – 51**	19	20
Peak Horiz Disp Head CG relative to non-rotating T1 (mm)	**106 – 132**	**96**	**85**
Peak Vertical Disp Head CG relative to T1 (mm)	**63 – 96**	**43**	**34**
Time of peak Head Excursion (msec)	**151 – 166**	180	173
Peak lateral head accel (G)	**7 – 9**	9	9
Peak vertical (downward) head accel (G)	**7 – 8**	7	6
Peak head flexion angle (deg)	**48 - 65**	**57**	**47**
note: shaded areas indicate measurements out of specifications note: **red text** indicates dummy responses that are somewhat different between the Original and FRG; **red boxes** indicate measurements made via high-speed video			

Figures 69-72 show overlays for the Original and FRG SID-IIs dummies for T1 lateral acceleration, shoulder Y force, upper neck X moment, and shoulder Y displacement for ISO Neck Test 1/Shoulder Test 2. These results indicate that the dummies responded similarly, except for a small variation in the peak shoulder Y force where the FRG exhibited a slightly higher response (approximately 770N for the FRG vs. 650N in the Original SID-IIs).

The results from ISO Neck Test 3/Shoulder Test 3 are presented in Table 22. In all but the case of the peak lateral T-1 acceleration (for which the Original fell slightly above the specification), both the Original and the FRG SID-IIs dummies passed or failed the same criteria. Although the peak head acceleration responses for both dummies are low with respect to the target biomechanical responses, both dummies responded similarly. The peak horizontal displacement of the head cg relative to the sled is 10mm less with the FRG than with the Original. This measurement is a result of motion in the head, neck, and shoulder; as in Neck Test 1/Shoulder Test 2, this measurement is also established using high-speed video analysis, and may contain error. Since the head displacements (relative to T-1) in Neck Test 1/Shoulder Test 2 were also lower for the FRG (11mm y-direction, 9mm z-direction), and were not affected by the FRG modifications, perhaps the difference in the measurement in Neck/Shoulder Test 3 is also *not* due to the modifications. Figures 73 – 75 show comparison plots between the Original and FRG SID-IIs dummies for T1 lateral acceleration, upper neck X moment, and shoulder Y displacement for Neck Test 3/Shoulder Test 3 and indicate that the dummies responded similarly. As in Neck Test 1/Shoulder Test 2, a small variation in the peak shoulder Y force (Figure 76), for which the FRG exhibited a slightly higher response (1030N with Original vs. 1190N with FRG), was evident.

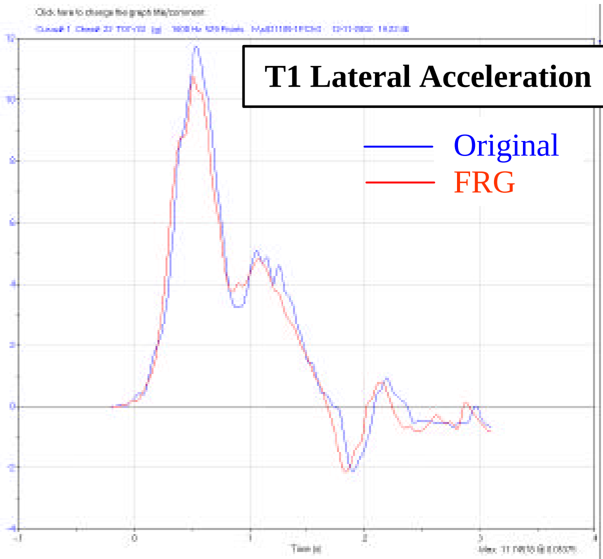


Figure 69. T1 lateral acceleration of the Original and FRG SID-IIs dummies in Neck Test 1/Shoulder Test 2

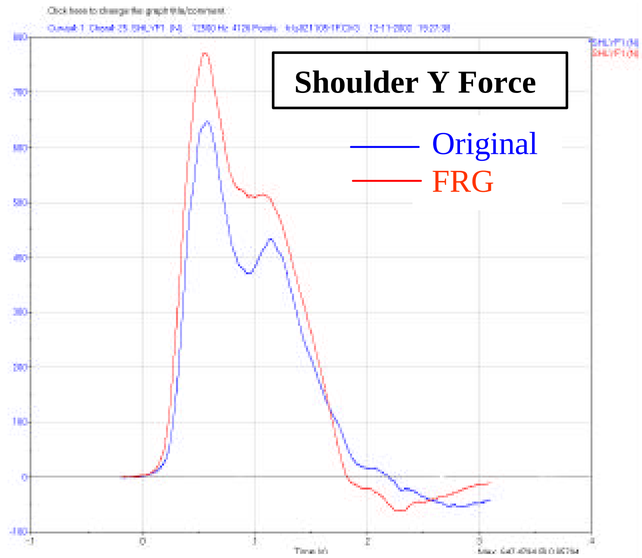


Figure 70. Shoulder Y Force of the Original and FRG SID-IIs dummies in Neck Test 1/Shoulder Test 2

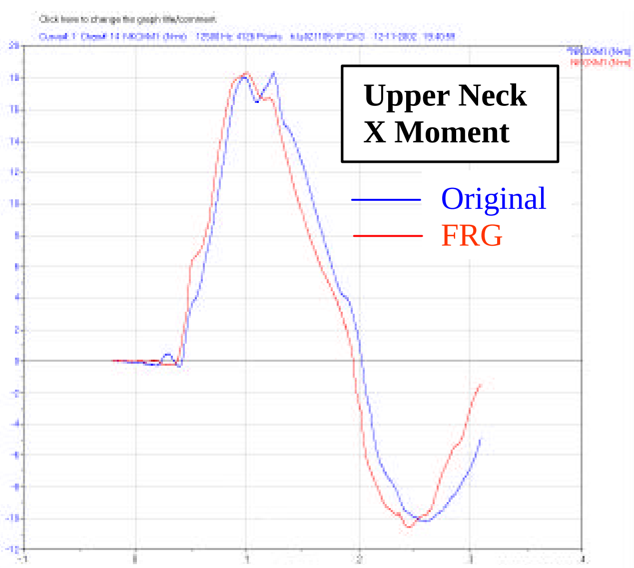


Figure 71. Upper neck X moment for the Original and FRG SID-IIs dummies in Neck Test 1/Shoulder Test 2

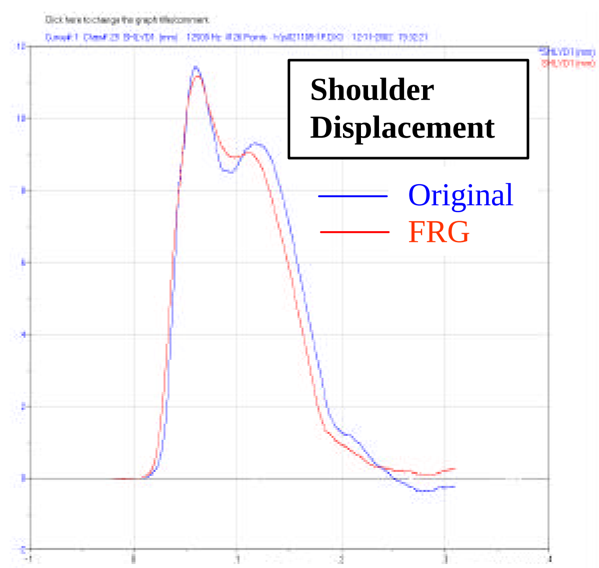


Figure 72. Shoulder displacement of the Original and FRG SID-IIs dummies in Neck Test 1/Shoulder Test 2

Table 22. ISO Neck Test 3/Shoulder Test 3 Results From Sled Series VII

ISO Neck Test 3/Shoulder Test 3 (12.2 G)		SN 56	SN 33
		Orig	**FRG**
	Spec Bounds	**S021105-2**	**S021106-3**
Peak Lateral Accel T1 (G)	**14 -19**	20	19
Peak Lateral Head CG Accel ((G)	**21 - 39**	13	14
Peak Horiz Disp Head CG relative to sled (mm)	**151 - 185**	**150**	**140**
Peak head flexion angle (deg)	**68 - 82**	72	70
note: shaded areas indicate measurements out of specifications note: **red text** indicates dummy responses that are somewhat different between the Original and FRG; **red boxes** indicate measurements made via high-speed video			

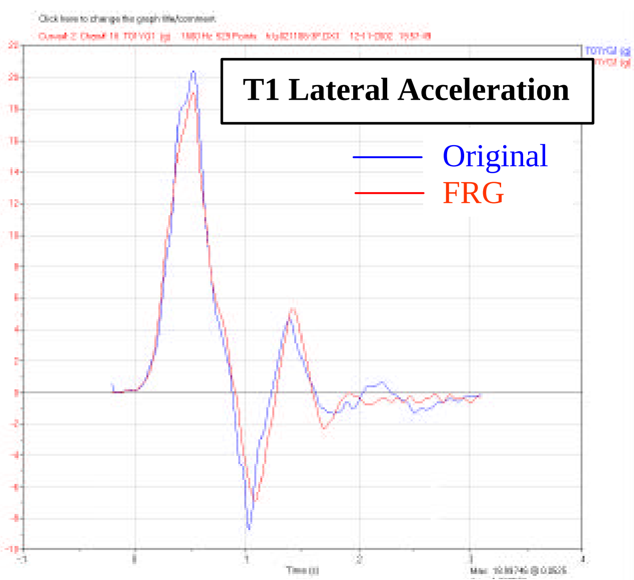


Figure 73. T1 lateral acceleration of the Original and FRG SID-IIs dummies in Neck Test3/Shoulder Test 3

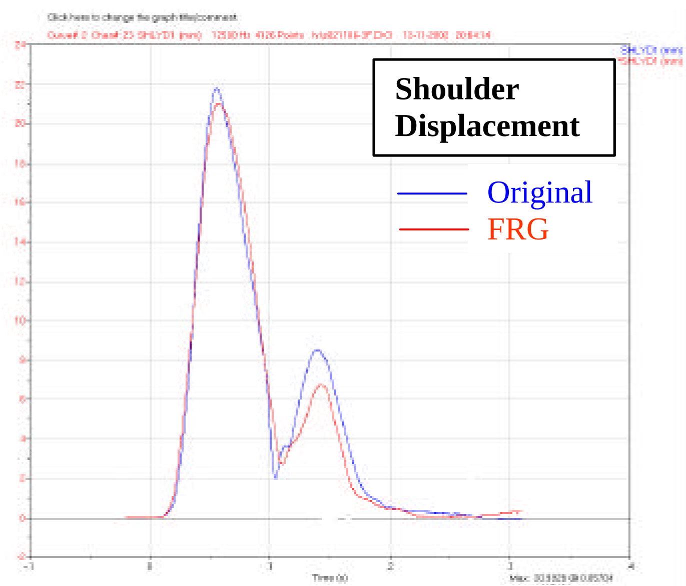


Figure 74. Shoulder displacement of the Original and FRG SID-IIs dummies in Neck Test3/Shoulder Test 3

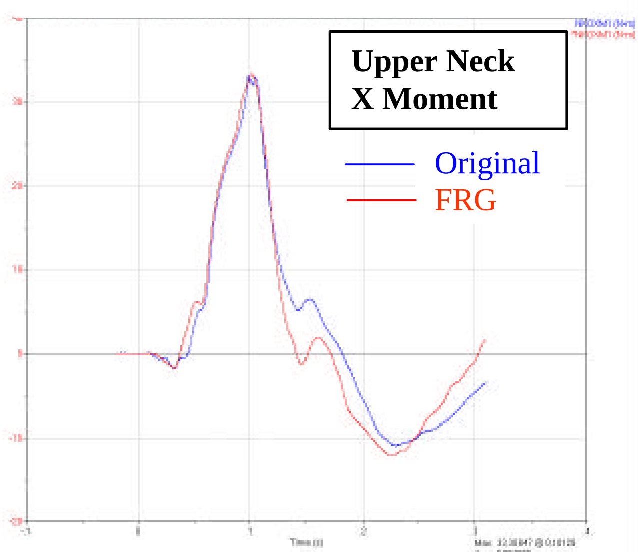


Figure 75. Upper neck X moment of the Original and FRG SID-IIs dummies in Neck Test3/Shoulder Test 3

Figure 76. Shoulder Y force of the Original and FRG SID-IIs dummies in Neck Test3/Shoulder Test 3

7.5.2 Padded Flat Wall Tests at 6.7 and 8.9 m/s

A total of four padded, flat wall tests were conducted during Sled Series VII (Table 20). Each dummy was tested once at a velocity of 6.7 and 8.9 m/s. Recall that biofidelity corridors for the SID-IIs, a small female, were obtained by scaling corridors for the 50th percentile male presented by Maltese (2002). Since a quantitative comparison of biofidelity responses between the Original SID-IIs and the FRG has not been conducted at this time, test results for each dummy were qualitatively compared both to the biofidelity corridors as well as to one another in order to assess differences in response between the two dummies (Figures 77 – 85).

In the low speed (6.7 m/s), padded, flat wall tests (LPF), the two dummies exhibited similar responses. This indicates that the FRG is comparable to the Original design in an LPF configuration. The FRG modification does not significantly change the biofidelity of the dummy in this condition.

In the high speed (8.9 m/s) padded, flat wall tests (HPF), pelvic accelerations and pelvic and abdominal plate forces are comparable between the Original and FRG. The peak thoracic force and T1 acceleration are approximately 17% and 20% larger, respectively, with the FRG compared to the Original dummy. FRG rib deflections are 4-5mm smaller than the Original, approximately a 7 - 12% difference. However, the FRG does not experience the “flat-top” event present in the abdominal rib deflection of the Original dummy (Figure 82).

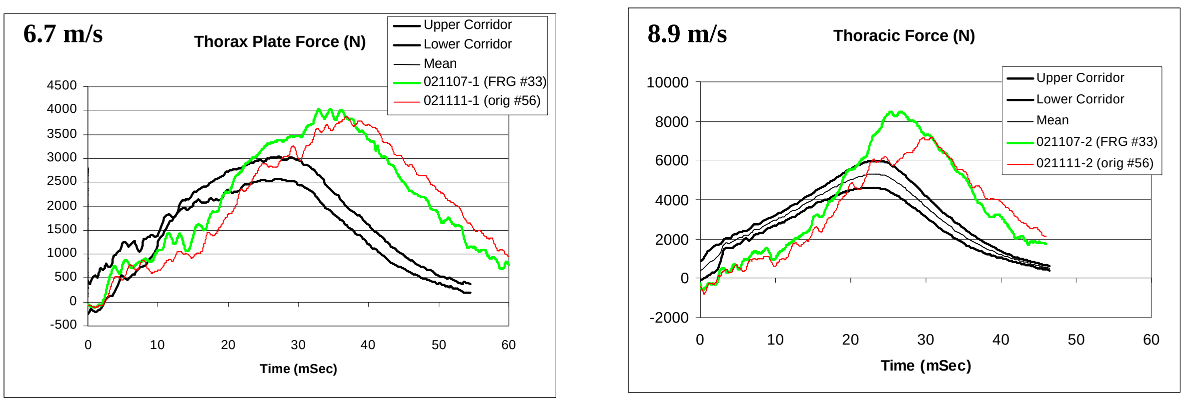


Figure 77. Thoracic plate force response and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

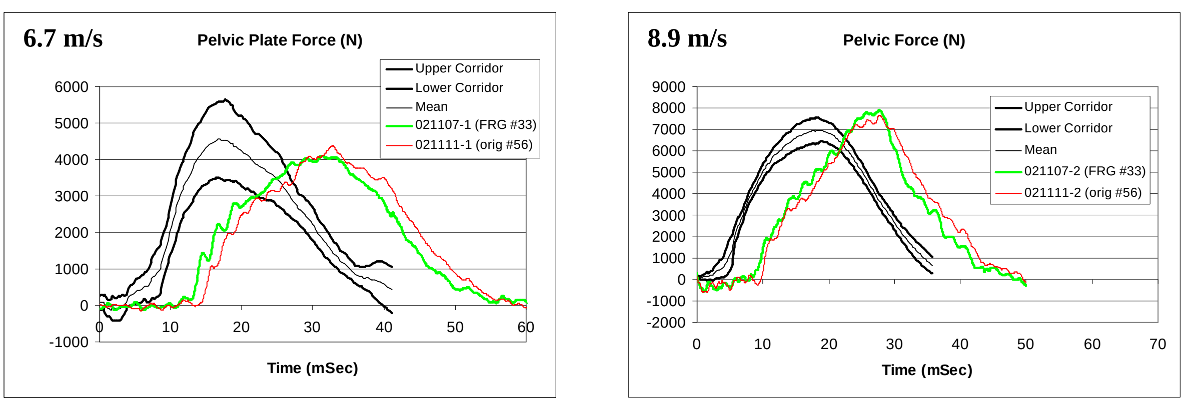


Figure 78. Pelvic plate force response and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

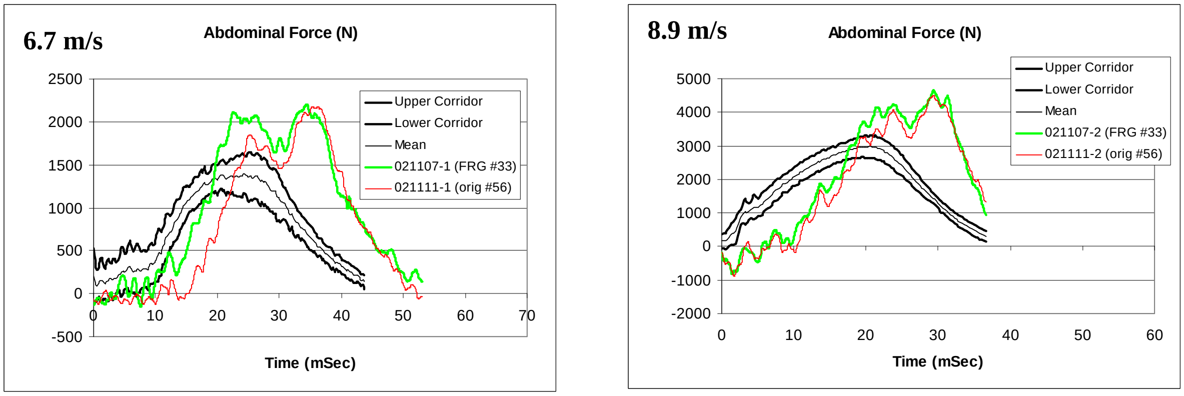


Figure 79. Abdominal plate force responses and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

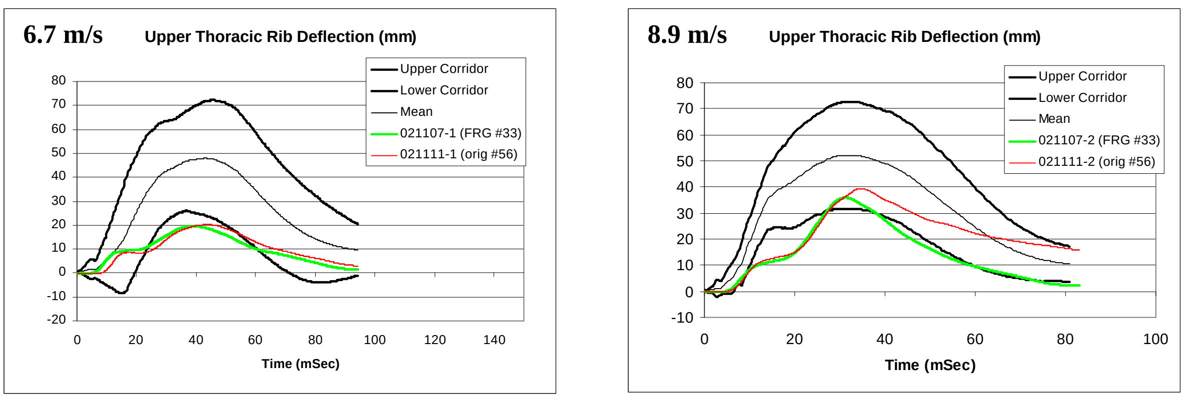


Figure 80. Upper thoracic rib deflection and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

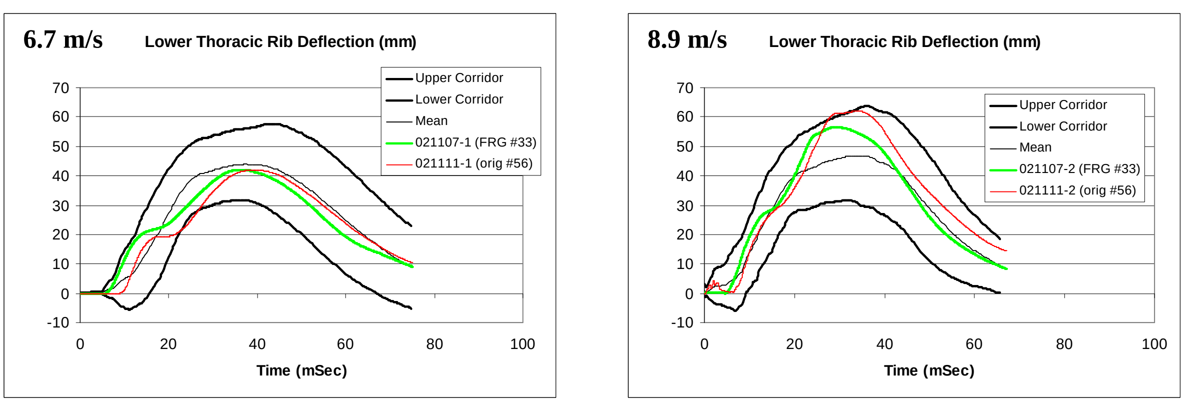


Figure 81. Lower thoracic rib deflection and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

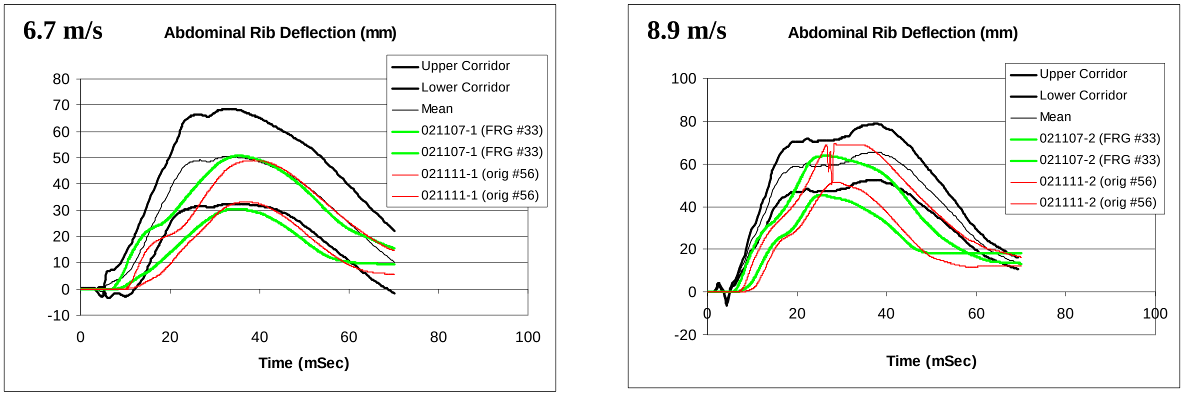


Figure 82. Abdominal rib deflection (both ribs are shown) and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

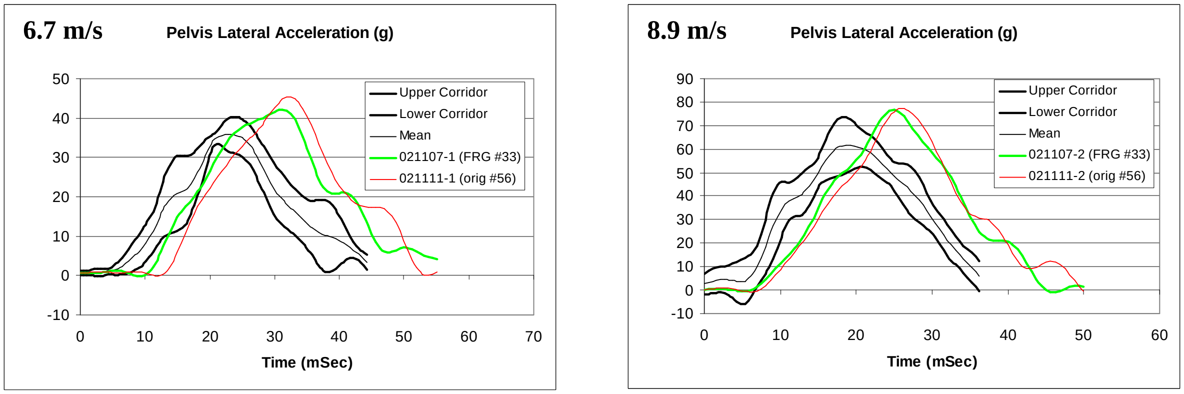


Figure 83. Pelvis lateral acceleration dummy responses and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

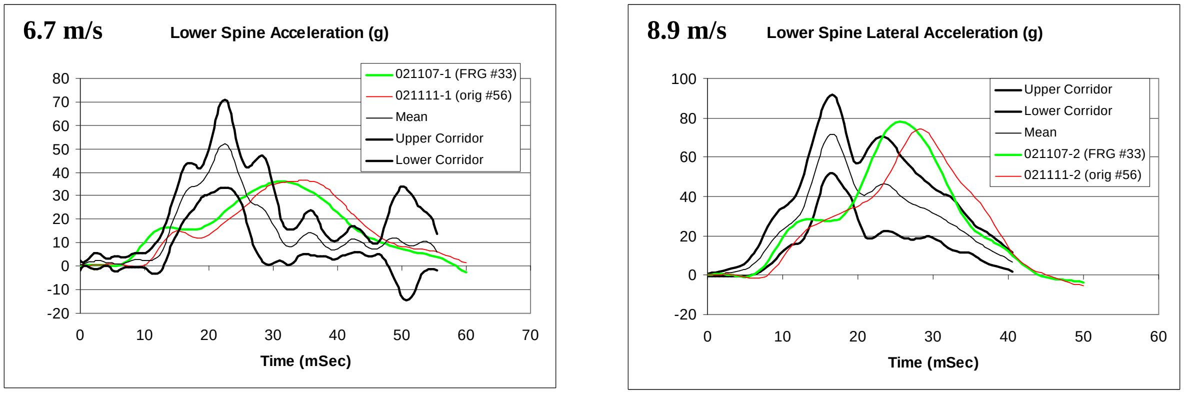


Figure 84. Lower spine lateral acceleration dummy responses and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

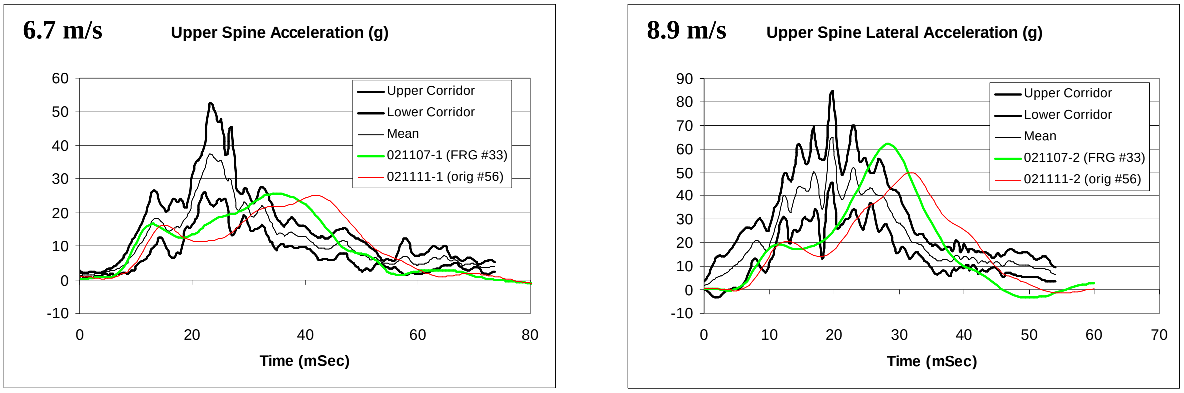


Figure 85. Upper spine lateral acceleration dummy response and biofidelity corridors for 6.7m/s and 8.9m/s padded flat wall tests

7.5.3 Summary of Results: Biofidelity Sled Series VII

In comparison ISO Neck Biofidelity tests, the FRG responds similarly to the Original, with the exception of a slightly larger lateral shoulder force. In Low-speed Padded Flat Wall Tests, the FRG responds similarly to the Original and no significant change in Biofidelity is apparent. However, in the High-speed Padded Flat Wall Tests, the FRG exhibited the following differences from the Original: 17% larger thorax wall forces, 20% larger T1 accelerations and 7-12% smaller deflections. During higher speed impacts, the FRG dummy appears to show a somewhat stiffer response. Figure 86 presents a summary of the results of this test series.

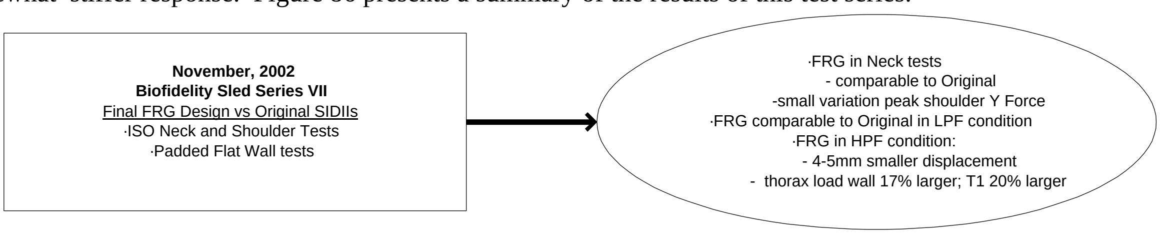


Figure 86. Summary of results for Biofidelity Sled Series VII

7.6 Dynamic Compression Test Series II (January 2003)

In January 2003, a second set of dynamic impact tests was undertaken to compare the Original SID-IIs to the final FRG SID-IIs in oblique impact environments since the rear seat occupant of the FMVSS 214 test often experiences an oblique impact. The test setup was designed to load the ribs of each dummy design in a controlled manner in order to examine the mechanism of the designs. The setup was not intended to replicate a vehicle crash test impact condition.

The thorax was rigidly mounted and impacted as in Dynamic Compression Test Series I (Figure 55). Thirty-two (32) tests were conducted at velocities between 4.4 and 8.1 mph (Table 23). Test velocities of 5.5 mph and 6.6 mph were selected for comparison of the Original and FRG SID-IIs dummies at impact angles of 0º, 15º, and 30º. To achieve the desired oblique angle, the dummy thorax was rotated about its center and the impact was directed toward the front of the dummy. These speeds were selected because they resulted in deflections between approximately 40mm and 55mm in a pure lateral mode; this deflection range was considered optimal as it encompassed a moderate amount of deflection without rib stop contact. Also, in some cases, one or both of the FRG cover plates were removed from the FRG thorax in order to ascertain the influence of the FRG cover plates on deflection measurements by comparison with the standard FRG (with front and back cover plates), and Original SID-IIs dummies. Recall that without the cover plates, the rib guides do not float with the ribs as they expand in the A-P direction. In order to eliminate variability caused by differences in rib sets, the same ribs were tested on both the FRG and Original SID-IIs dummies.

Table 23. Test Matrix for Dynamic Compression Test Series II (January 2003)

Number of Tests Conducted	Velocity (mph)	Original SID-IIs	FRG	FRG without backplate	FRG no plates	Frontal Oblique Angle (deg)	Test Nos.
1	4.4		X			0	1
1	8.1		X			0	2
1	7.2		X			0	3
1	5.3		X			0	4
2	5.5 – 5.6		X			0	5, 6
1			X			15	31
2			X			30	17, 19
3		X				0	22, 23, 24
1		X				30	21
2				X		0	9, 10
2				X		15	30, 32
2				X		30	13, 14
3	6.6 – 6.7		X			0	7, 8, 27
2			X			30	18, 20
2				X		0	11, 12
2				X		30	15, 16
2		X				0	25, 26
2					X	0	28, 29

For this test series, all ribs were impacted simultaneously with a 3 ½" wide vertical wood block, which extended the length of ribs 1 through 5. Figure 87 shows examples of test setups for the 0º and 30º (towards the front) test configurations.

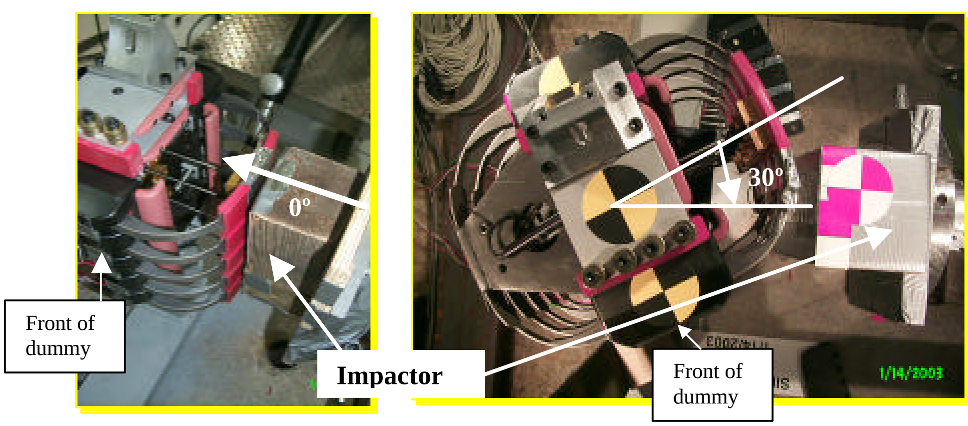


Figure 87. Test configurations for non-oblique (0º) and 30º (towards the front) oblique impacts

Table 24 shows the maximum deflection values for this test series. In order to compare the dummy designs, a definition for equivalent responses was assigned. For dummy responses to be considered "equivalent", the difference between average deflections (if multiple tests were performed) should be less than or equal to 4mm. Deflection differences 5mm or greater were considered "non-equivalent".

Table 24. Comparison between the Final FRG and Original SID-IIs during Dynamic Compression Series II

Dummy Configuration	Velocity (mph)	Oblique Angle (deg)	Test #	Rib1 Disp (mm)	Rib2 Disp (mm)	Rib3 Disp (mm)	Rib4 Disp (mm)	Rib5 Disp (mm)
Original	5.5-5.6	0	22	**	**	**	**	**
			23	*	41	*	42	*
			24	*	42	*	42	*
FRG			5	38	39	40	41	42
			6	37	39	39	40	41
FRG w/o Back Plate			9	38	39	39	40	41
			10	40	41	41	42	43
FRG		15	31	**29**	**30**	**31**	**31**	**33**
FRG w/o Back Plate			30	**30**	**30**	**31**	**31**	**33**
			32	**31**	**32**	**32**	**32**	**33**
Original		30	21	*	**21**	*	**20**	*
FRG			17	**21**	**21**	**22**	**19**	**20**
			19	*	**22**	*	**20**	*
FRG w/o Back Plate			13	**23**	**23**	**24**	**22**	**22**
			14	**22**	**22**	**22**	**20**	**21**
Original	6.6-6.7	0	25	**52**	**53**	**53**	**54**	**56**
			26	**51**	**52**	**53**	**53**	**55**
FRG			7	**45**	**47**	**47**	**48**	**50**
			8	**47**	**48**	**48**	**49**	**51**
			27	**46**	**46**	**47**	**48**	**48**
FRG w/o Back Plate			11	49	51	51	52	53
			12	47	48	49	49	51
FRG No Cover Plates			28	49	50	51	54	52
			29	49	50	50	50	52
FRG		30	18	**22**	**22**	**23**	**20**	**21**
			20	*	**23**	*	**20**	*
FRG w/o Back Plate			15	**23**	**23**	**23**	**21**	**21**
			16	**23**	**23**	**23**	**22**	**22**

* Not recorded to limit possibility of multiple potentiometer damage
** Invalid Test
Note: values in **RED** indicate "non equivalency" between the FRG and Original SID-IIs
Note: values in **BLUE** indicate rib contact with rib stop and/or spine box

Out of three directly comparable cases between the Original and FRG SID-IIs (5.5 mph 0 and 30 degrees and 6.6 mph 0 degrees), only one case showed a noticeable difference in the deflection measurements between them (6.6 mph 0 degree tests, red text in Table 24). The 5.5 mph 0 degree tests showed similar deflection measurements for both the Original and FRG. The 5.5 mph 30 degree tests showed rib-to-rib stop contact for both designs (denoted by blue text in Table 24), which limited the amount of deflection that could be measured. The 6.6 mph, 0° impact comparison between the FRG and Original SID-IIs dummies was the only configuration which provided deflection differences of 5mm or more. For this comparison, average deflections for four out of five of the ribs experienced deflection differences of 6mm (Table 25). The only exception was Rib 2, where the difference between the average deflections was 5mm.

Table 25. Comparison between the Final FRG and Original SID-IIs in 6.6 mph, 0° Impacts during Dynamic Compression Series II

	Test #	Rib1 Disp (mm)	Rib2 Disp (mm)	Rib3 Disp (mm)	Rib4 Disp (mm)	Rib5 Disp (mm)
Original	25	52	53	53	54	56
	26	51	52	53	53	55
Average		**52**	**52**	**53**	**54**	**56**
FRG	7	45	47	47	48	50
	8	47	48	48	49	51
	27	46	46	47	48	48
Average		**46**	**47**	**47**	**48**	**50**
D **Average**		**6**	**5**	**6**	**6**	**6**

The plots in Figure 88 illustrate deflections for examples of 6.6 mph, 0° comparison for 2 tests (Tests 27 and 26). The difference in the deflection data traces between the FRG and Original dummies suggests that, at 6.6 mph during a purely lateral dynamic compression test, the FRG response is somewhat stiffer.

In oblique impact situations during this test series, both the Original and FRG SID-IIs dummies experienced limited deflection when compared to purely lateral impacts. During an oblique, frontal impact event, the ribs of the SID-IIs (both Original and FRG) are pushed towards the rear, which causes the potentiometers to pivot about their mountings at the center of the dummy and "swing" rearward (Figure 89, 90). The pot swing during oblique impacts causes much less deflection to be measured compared to pure lateral impacts because the potentiometers are not measuring deflection in the line of action of the applied force. Additionally, in an oblique impact, depending on the degree of obliqueness of the impact, the ribs may contact the rib stop and/or the frontal edge of the spine box (blue text in Table 24), restricting further rib deflection. Even a small impact angle, such as 15°, results in a significant reduction in the rib deflection measurement (Figure 91) due to pot swing and rib-to-rib stop contact.

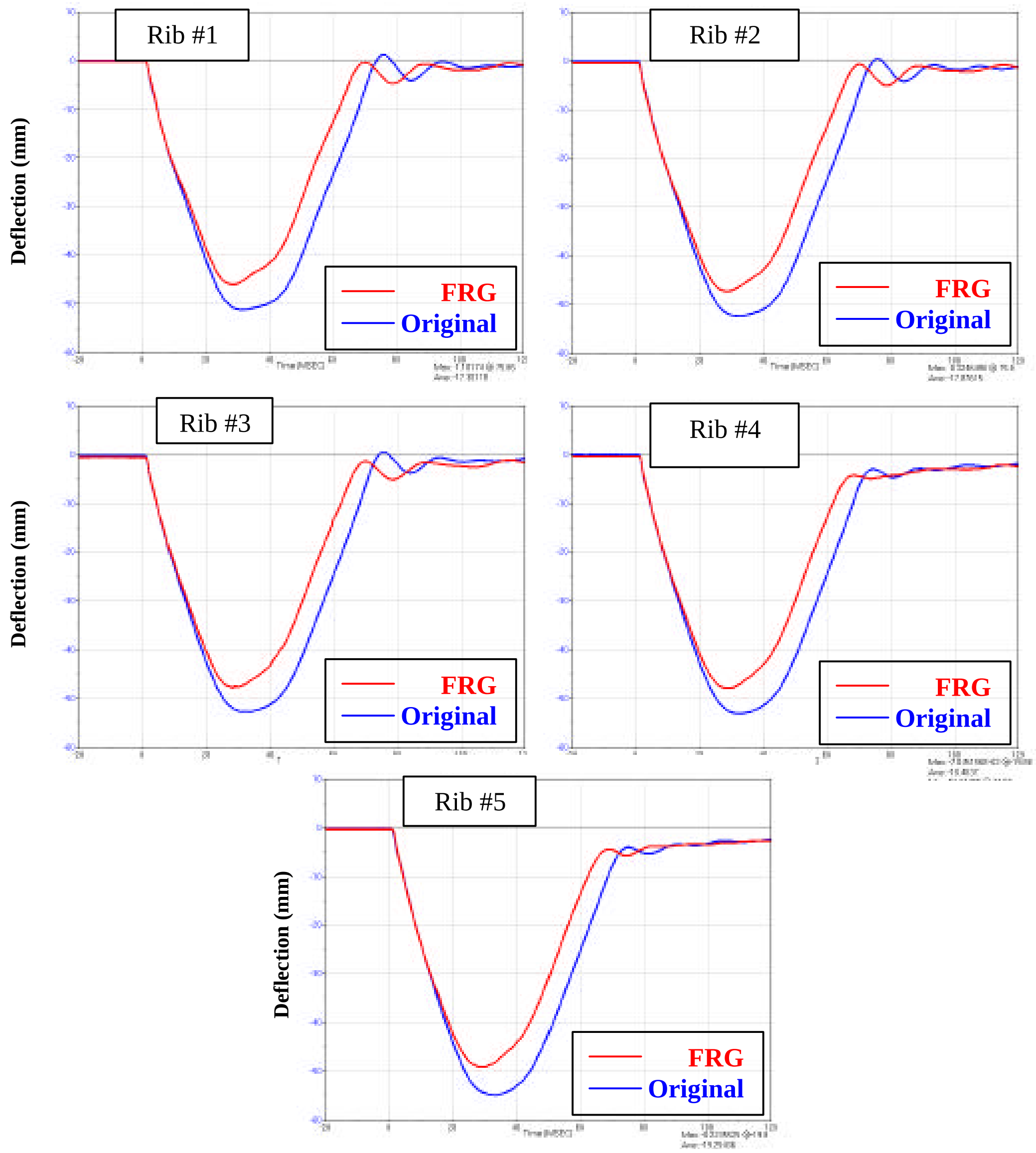


Figure 88. Comparison overlays between the FRG (Test 27) and Original (Test 26) SID-IIs in 6.6 mph, 0° impacts

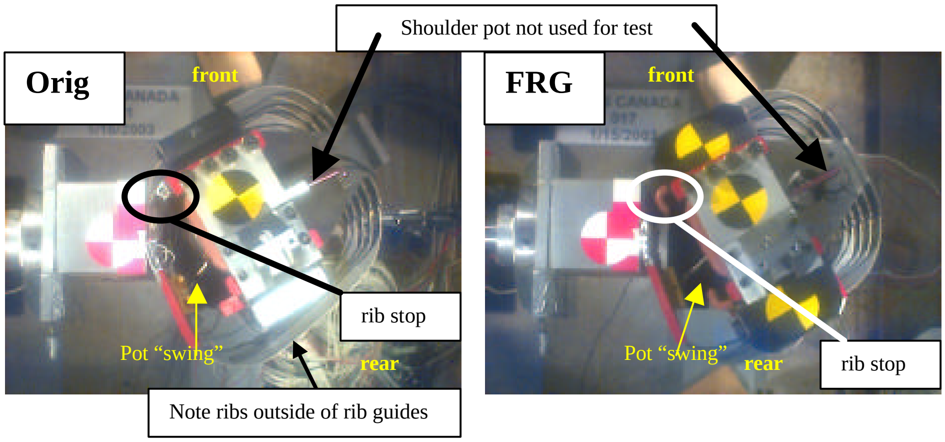


Figure 89. Rib deflection is limited by rib contact with the rib stops in both the Original (Test 21) and FRG (Test 17) SID-IIs dummies during oblique impact. Impact shown is 30° oblique.

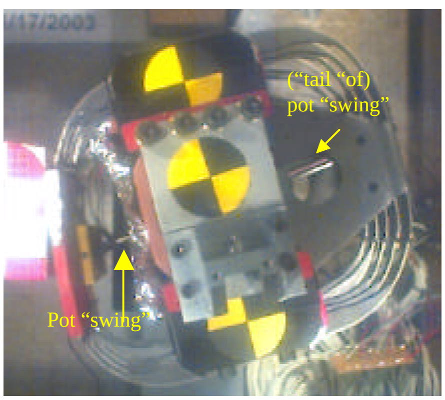


Figure 90. Potentiometer “swing” in a 15° oblique FRG test (Test 30)

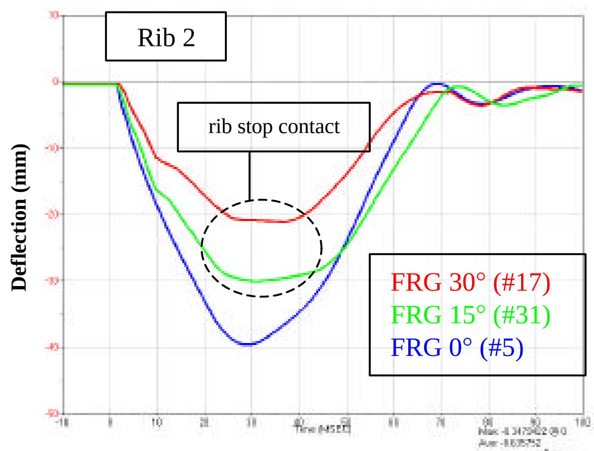


Figure 91. Effect of increasing oblique angle on FRG SID-IIs rib deflection

Even at small oblique impact angles, such as 15°, the rib contacts the rib stops and/or edge of the spine box, limiting deflection (Figures 89, 92); on both dummies, the ribs tend to “wrap” around the front edge of the spine box and front rib stop (Figure 93). Although physical evidence (contact marks) indicated that the ribs were contacting the rib stops in oblique tests, in Tests 21 – 32, contact switches were added on both the front and lateral edges of the rib stops to identify when contact occurred. Figure 94 illustrates the contact of rib 2 with the rib stop on the Original SID-IIs in a 30° oblique impact (Test 21). Note that the shape of the deflection curve changes upon contact with the rib stop, which first occurs at approximately 13 mm of measured lateral rib deflection.

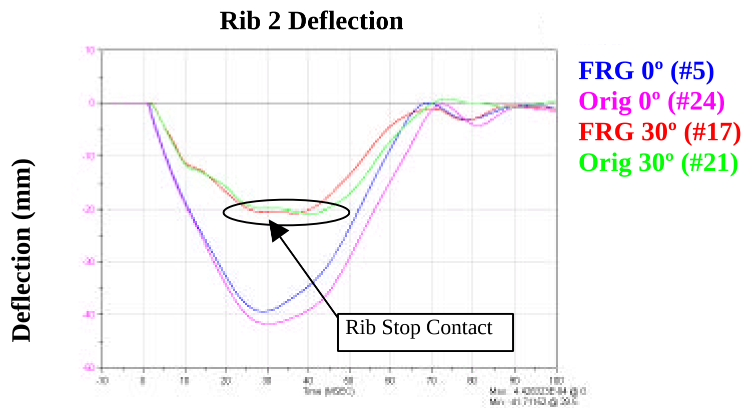


Figure 92. Comparison between Original and FRG SID-IIs rib deflections at 0° and 30° impact angles at 5.5 mph

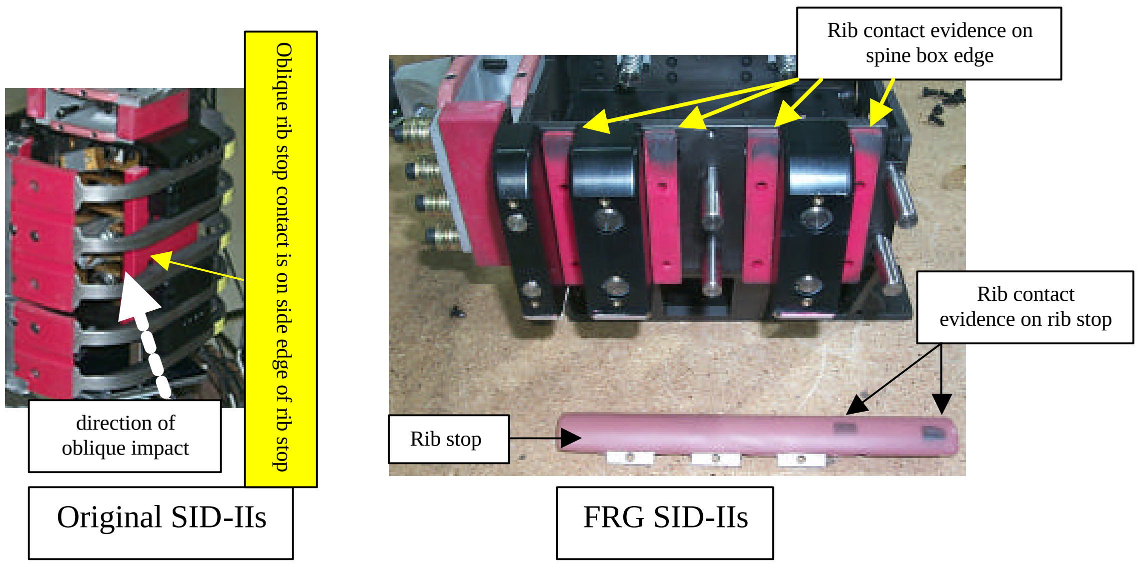


Figure 93. Contact points during oblique impacts for the Original and FRG SID-IIs dummies.

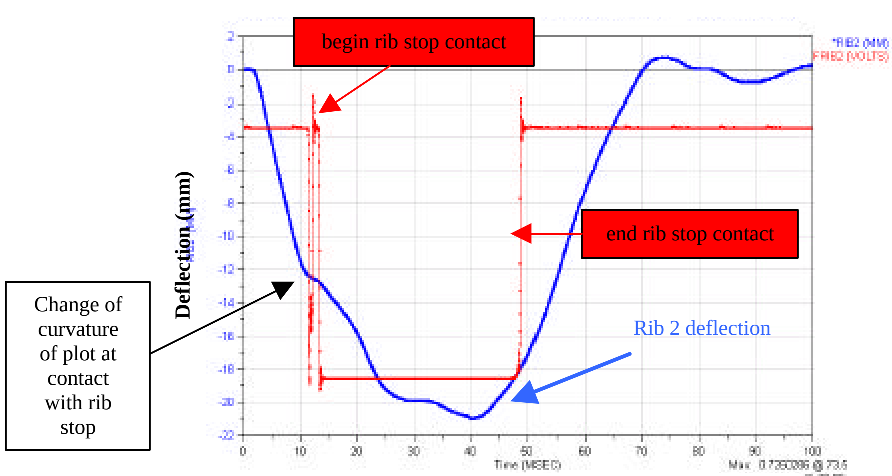


Figure 94. Rib contact with rib stop (at 13 mm) on the Original SID-IIs (Test 21) during 30° oblique impact

In addition, a comparison between low-speed and high-speed impacts to the FRG at a 30° oblique angle reveals that the deflection does not increase, even with increased energy, due to rib stop contact and potentiometer pivot (Figure 95). This phenomenon occurs in both FRG and Original SID-IIs dummies.

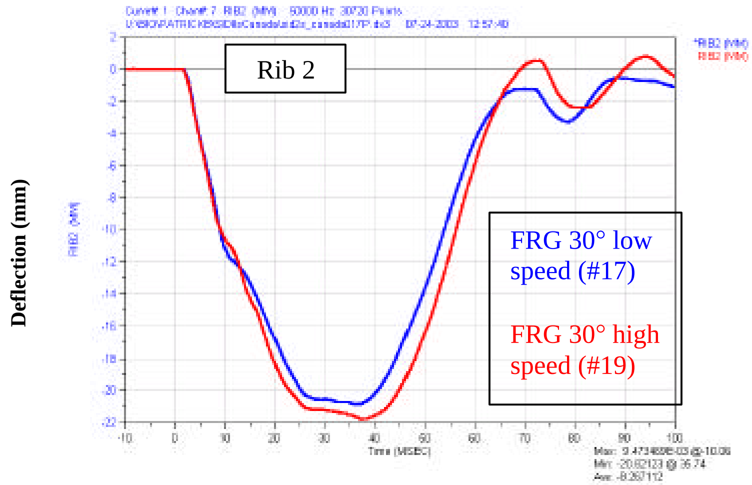


Figure 95. Rib deflection is not affected by increased impact velocity when ribs are in contact with rib stops

In order to assess the effect of the cover plates of the Floating Rib Guide system, only some of the data from this test series could be used. Since the deflections during 15 and 30 degree impacts were limited by contact with the rib stops, that data was not used for comparison. And since the 5.5 mph 0 degree data is quite similar between the FRG and Original dummies, it was not utilized for comparison either. However, if the 6.6 mph 0 degree impact data with the FRG with no back plate and FRG with no cover plates are considered, the FRG plates do appear to slightly increase the stiffness response of the dummy. For example, in Table 26, the range of average peak deflections increases in the following order: FRG; FRG no back plate; FRG no cover plates; Original, indicating that as the FRG plates are added, the stiffness response increases.

Table 26. Average Rib Deflections during 6.6 mph 0° Impacts

	Average Deflection					Range of Average Peak Deflections
	Rib 1	Rib 2	Rib 3	Rib 4	Rib 5	
Original	51.5	52.5	53.0	53.5	55.5	51.5-55.5
FRG	46.0	47.0	47.3	48.3	49.7	46.0-49.7
FRG no back plate	48.0	49.5	50.0	50.5	52.0	48.0-52.0
FRG no cover plates	49.0	50.0	50.5	52.0	52.0	49.0-52.0

Figure 96 presents a summary of the results of this test series. In the configurations tested, the FRG rib deflection was equivalent to the Original SID-IIs in nearly all cases. The only exception was a 6.6 mph, pure lateral impact, where the FRG peak deflections on average were up to 11% smaller than those of the Original. The stiffer response of the FRG dummy was also evident in HPF tests during Sled Series VII, in which deflections were 7-12% smaller than those of the Original. Although the FRG exhibited stiffer responses, including increased upper spine acceleration and thorax wall forces, its Biofidelity was not significantly different from that of the Original and its durability was improved.

The stiffer response of the FRG has been observed during dummy evaluation tests with rib deflections *larger* than 45 mm. Crash data with the SID-IIs FRG, including four Oblique Pole tests, two FMVSS 214 tests, and two Side NCAP tests, totaling eleven dummy exposures, show peak deflections in the range of 23-59 mm, with an average of 38 mm. Since the crash environment exercises the dummy such that rib deflections larger than 45 mm have been observed, the stiffer response of the FRG may be observed in the crash environment. Since the Biofidelity of the

FRG was not significantly different from that of the Original, the FRG dummy responses will relate to cadaver injury data just as well as that of the Original. Finally, the FRG dummy exhibits improved durability over the Original SID-IIs.

Additionally, oblique impacts significantly reduced the rib deflection measurements; small changes in impact angle resulted in significant differences in rib deflection. This was true both of the FRG and the Original dummies. "Pot swing" was noted as the cause for the decreased deflection measurements, along with possible rib contact with the spine box and/or rib stops.

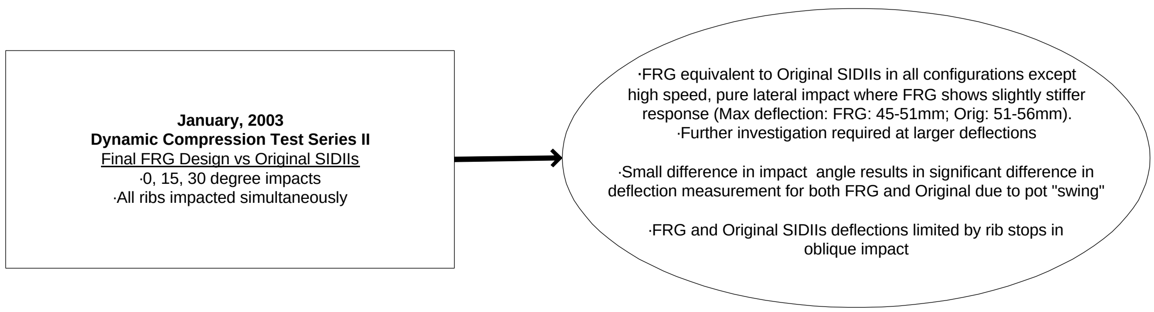


Figure 96. Summary of Dynamic Compression Test Series II

7.7 Dynamic Compression Test Series III (March 2003)

In March 2003, a third dynamic compression test series was conducted with only the FRG dummy. In the previous test series, the impact head was directed at all ribs simultaneously. The objective of Test Series III was to examine the influence of localized loading and various combinations of oblique (rotate thorax about Z axis), upward (rotate thorax about X axis), and "leanback" angles (rotate impact face about Y axis) of either 0° or 20° (Table 27) on the deflection responses of the FRG dummy. The velocity selected for testing was approximately 4.9 mph; this velocity resulted in peak rib deflections of 45mm – 53mm in a purely lateral mode (moderate amount of deflection, but safe amount less than maximum rib stroke). Twenty-nine (29) tests were performed.

Table 27. Dynamic Compression Series III Test Matrix

Impact Location	Oblique Angle (deg)	Upward Angle (deg)	Armrest "Leanback" Angle (deg)
Ribs 4, 5 Ribs 3, 4 Center Rib 2	0	0	0
	0	20	0
	20	0	0
	20	20	0
Lower Ribs Upper Ribs	20	20	20

The tests were conducted with the same linear, hydraulic impactor (32.7 kg) and rigidly braced thorax fixture utilized in the previous test series. A simulated wood "armrest" was constructed and utilized as the impact face for these tests (Figure 97). The size and shape of this impact face (contact surface approximately 10" x 3" with ¼" rounded edges) allowed for localized deflection of two ribs (or three ribs depending on centering of the impactor). The 20° "leanback" angle was achieved by rotating the armrest to contact the thorax in the same manner as if the dummy were reclined in a seat during a side impact (Figure 98).

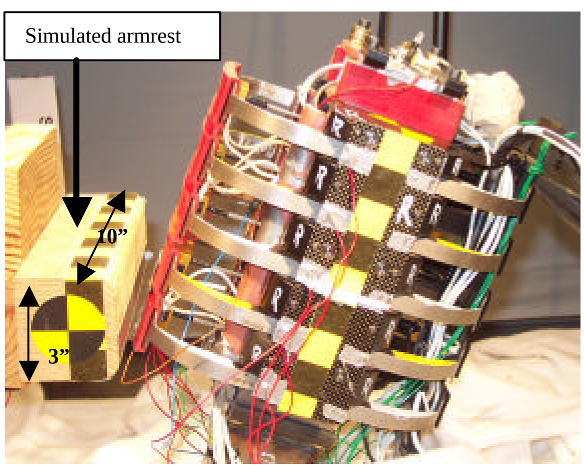


Figure 97. Setup for localized impacts conducted in Dynamic Compression Test Series III (setup is for a 0° oblique, 20° upward, 0° "leanback" impact to ribs 4,5)

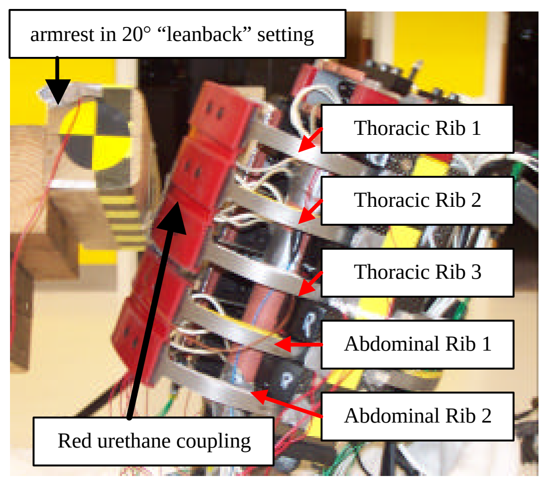


Figure 98. Setup for "leanback" impacts conducted in Dynamic Compression Test Series III (setup is for a 20° oblique, 20° upward, 20° "leanback", impact of upper ribs)

Table 28 shows the peak rib deflections for the tests conducted during Dynamic Compression Series III. The FRG tests appear repeatable. This table shows that deflections are influenced by several criteria, including "coupler drag", upward impacts, and oblique impacts. For all tests conducted multiple times, results indicate a repeatable test condition based on dummy peak rib deflections.

Table 28. Comparison FRG Impacts in Upward, Oblique, and "Leanback" Configurations at 4.9 mph

Oblique Angle (deg)	Upwards Angle (deg)	"Leanback" Angle (deg)	Test # SID2sOBQ_	Rib1 Disp (mm)	Rib2 Disp (mm)	Rib3 Disp (mm)	Rib4 Disp (mm)	Rib5 Disp (mm)
Impact Ribs 4, 5 (primary contact rib is rib 5 for upward impact)								
0	0	0	03	-	-	-	53	52
			04	-	-	-	53	52
0	20	0	10	-	-	-	44	56
			11	-	-	-	41	54
20	0	0	16	-	-	-	**27**	**28**
20	20	0	20	-	-	-	20	**28**
			21	-	-	-	20	**28**
Impact Ribs 3,4 (primary contact rib is rib 4 for upward impact)								
0	0	0	08	-	**11**	44	45	**9**
			09	-	**11**	44	45	**10**
0	20	0	14	-	**7**	32	47	**13**
			15	-	**7**	32	47	**12**
20	0	0	19	-	**8**	23	**26**	**6**
20	20	0	24	-	**5**	19	**25**	**5**
			25	-	**5**	19	**25**	**5**
Impact Center Rib 2 (primary contact rib is rib 2 for upward impact)								
0	0	0	06	**40**	48	**41**	-	-
			07	**41**	48	**42**	-	-
0	20	0	12	**30**	47	**41**	-	-
			13	**30**	47	**41**	-	-
20	0	0	17	**16**	**31**	**27**	-	-
20	20	0	22	**19**	**27**	**21**	-	-
			23	**20**	**27**	**22**	-	-
Impact Lower Ribs								
20	20	20	26	-	**5**	19	**22**	**4**
			27	-	**5**	18	**22**	**4**
Impact Upper Ribs								
20	20	20	28	**15**	23	**22**	-	-
			29	**15**	23	**23**	-	-

Note: Values in **RED** indicate rib stop contact. Note: Values in **BLUE** indicate some degree of "coupler drag".

Ribs 1, 2, and 3 (thoracic ribs) are connected together via a flexible, (red) urethane coupler (Figure 98). The abdominal ribs, 4 and 5, are also joined together by the same flexible material. If a rib is directly impacted, the resulting deflection may be solely due to the impact. However, adjacent ribs (not directly impacted) may also experience deflection, but at a decreased magnitude. This is due to “coupler drag”, which occurs when adjacent ribs, “coupled” by the flexible (red) urethane material (Figure 98), are “dragged” along with the impacted ribs (Figure 99). It should be noted that this occurs in *both* the FRG and Original SID-IIs, and is simply a characteristic of the construction of the dummy. It is known that human ribs are coupled and respond as such, but it is not known how similar the coupled response of the SID-IIs ribs is to that of humans. This study was conducted to examine the effects of localized impacts to the FRG. One effect of localized loading is the reduced deflections of adjacent ribs due to the coupling material that is present in both the FRG and Original designs. Figure 100 shows the influence of coupler drag on deflections during a purely lateral test (Test 9) where ribs 3 and 4 were directly impacted. Ribs 2 and 5, although not directly impacted, are “pulled” along with ribs 3 and 4 during the event due to the thorax and abdomen couplers and achieve deflections of decreased magnitude. High-speed video indicated that “coupler drag” was responsible for the decreased magnitude of deflection of ribs 2 and 5 (Figure 99).

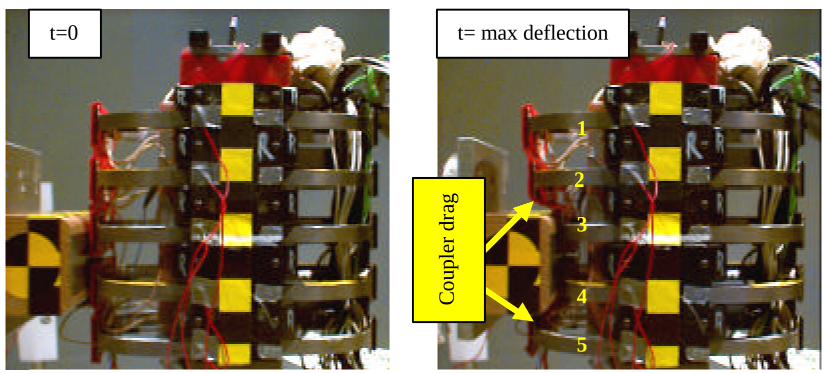


Figure 99. Lateral impact to ribs 3 and 4 illustrating “coupler drag” at ribs 2 and 5 (Test 9)

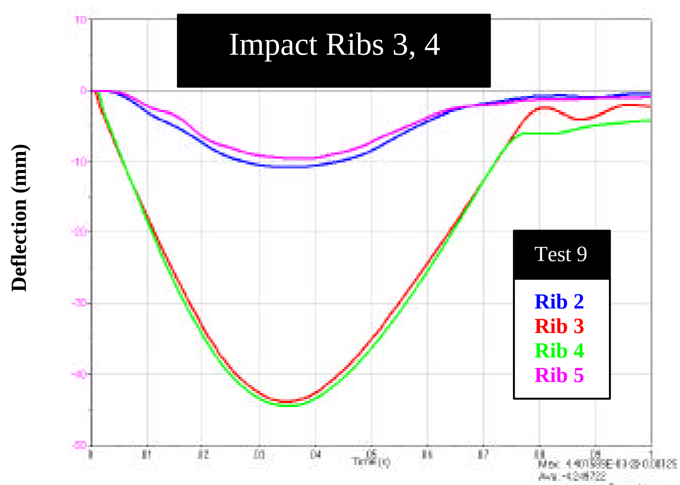


Figure 100. Pure lateral impact to ribs 3, 4 illustrating “coupler drag” of ribs 2 and 5

Rib deflections were also influenced by upward (or downward) forces, but only as a result of the geometry of the test setup. For the setup used in these tests, the upward force was achieved by rotating the thorax about the X-axis. As an example, Figure 101 illustrates the configuration for impact of ribs 4 and 5 (also known as abdominal ribs 1 and 2, respectively) during a 0° oblique, 20° upward, 0° "leanback" test (Test 11). Rib 5 is the first rib contacted ("primary" rib) and exhibits more deflection than rib 4 ("secondary" rib) due to prolonged contact. In Figure 102, the primary contact rib for the 20° upward impact, rib 5 (Test 11), gives a similar deflection to rib 5 in a pure lateral (0°) mode (Test 4). This illustrates that with the FRG, even in an upward mode, the primary contact rib gives similar deflection to a pure lateral impact. Rib 4, the secondary rib, exhibits less deflection due to the geometry of the impact setup; since rib 5 is contacted first, rib 4 experiences less contact time with the impact head. It is important to note that no damage occurred with the FRG during any of the upward tests.

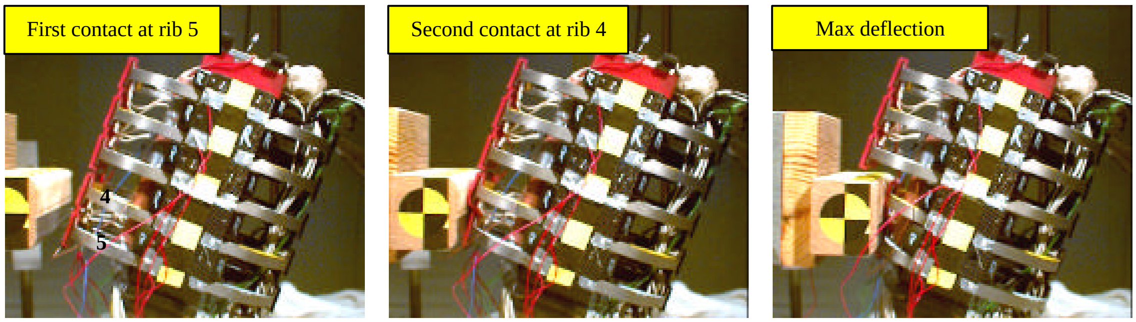


Figure 101. Impact to Ribs 4, 5 at 0° oblique, 20° upward (note: rib 5 is first ("primary") contact and rib 4 is second ("secondary") contact) (Test 11)

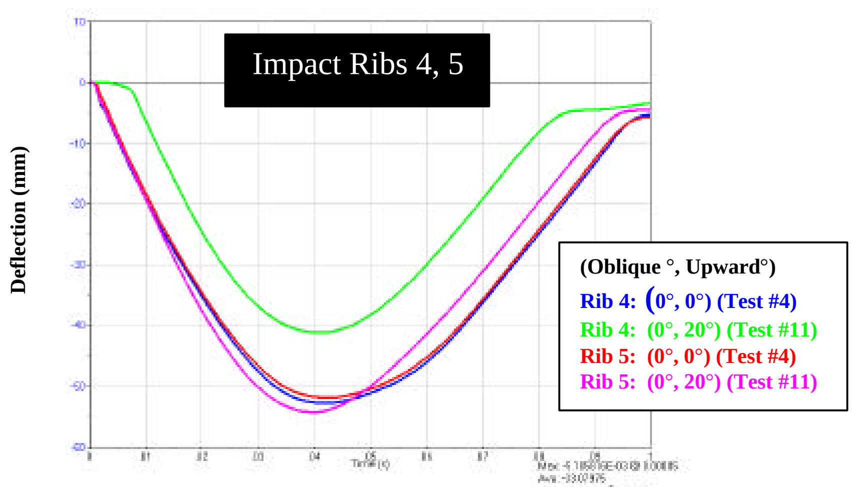


Figure 102. Plot overlay showing influence of upward angle on deflections (note that Rib 5 is the "primary contact" rib in the Rib 4, 5 impact)

The measurements found in Table 28 indicate that the most influential aspect controlling the magnitude of deflection is whether or not the impact included an oblique angle. Adding a 20° oblique angle to rib 4,5 impacts reduces primary contact rib deflection by nearly 50% compared to pure lateral or upward impacts (Figure 103).

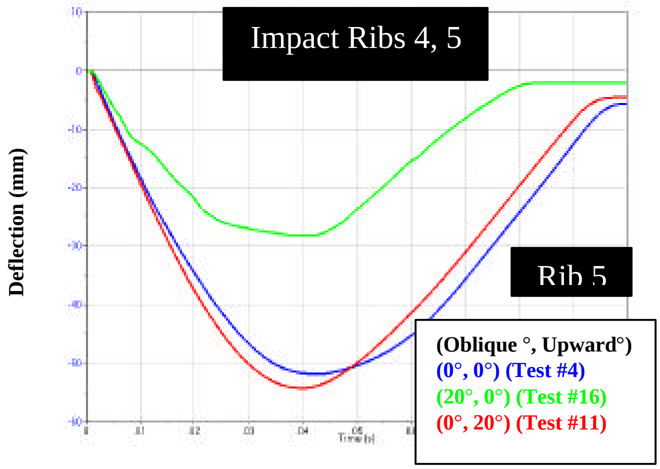


Figure 103. Plot overlay showing influence of oblique angle on deflections (note that Rib 5 is the "primary contact" rib in the Rib 4, 5 impact)

Video analysis reveals that the same "potentiometer swing" movement, as well as rib stop contact, discussed in Section 7.6 (Dynamic Compression Test Series II) is also the cause of the limited deflection in the oblique tests (Figure 104) during Test Series III.

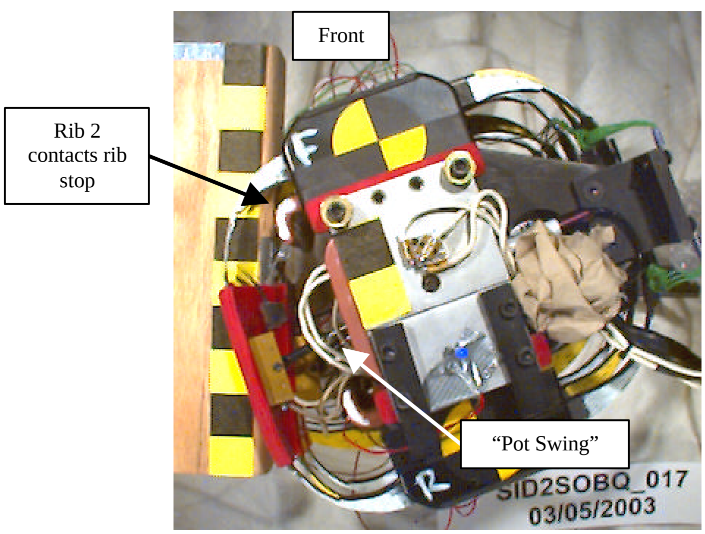


Figure 104. Illustration of "pot swing" and rib stop contact which limit deflection in oblique impacts in Dynamic Compression Series III (Test 17)

Figure 105 presents a summary of the results of this test series. When an upward component was applied to the FRG, no “rib jumping” was evident. No potentiometer damage to instrumentation was seen in these tests using the FRG. The FRG output in these tests was repeatable. As in the previous test series, in tests with an oblique input component, the rib deflection measurements were significantly less than in pure lateral impacts. This was attributed to “pot swing” and rib contact with the spine box and/or rib stop, which occurs in both the FRG and Original dummies. “Coupler drag”, caused by adjacent (non-impacted) ribs being “dragged” along due to the urethane rib coupling material (connecting all thoracic ribs and both abdominal ribs) also resulted in decreased deflections. However, this phenomenon is also evident in the Original SID-IIs and is not a result of the Floating Rib Guides.

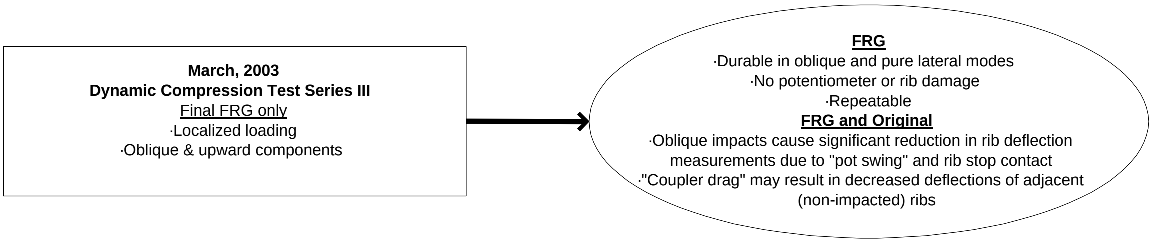


Figure 105. Summary of Dynamic Compression Series III

7.8 Dynamic Compression Test Series IV (April-May 2003)

This dynamic impact test series was conducted to compare the Original SID-IIs and the FRG in upward and oblique impacts. Forty-four (44) impact exposures, 27 of which were utilized for comparison, were conducted at straight lateral (0º oblique) and 15º oblique angles with varying degrees (0º, 5º, 10º, 15º) of upward directed input. Both dummies were tested in the same configurations for comparison. For this test series, either the FRG or Original SID-IIs thorax was placed in the rigid system described previously in Section 7.2. This allowed for easy adjustment of both the oblique (rotation about the Z axis) and upwards (rotation about the Y axis) rotations of the dummy. Figures 106 – 108 illustrate examples of the setup configuration for this series of tests.

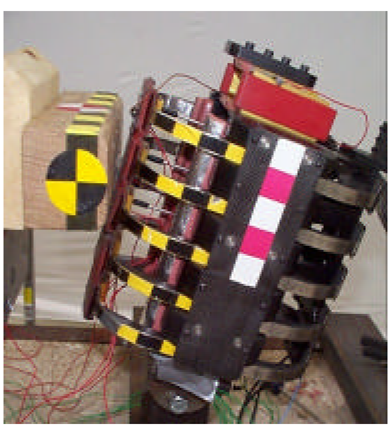


Figure 106. FRG setup in 0º oblique, 15º upward configuration

Figure 107. FRGset up in 15º oblique, 0º upward configuration

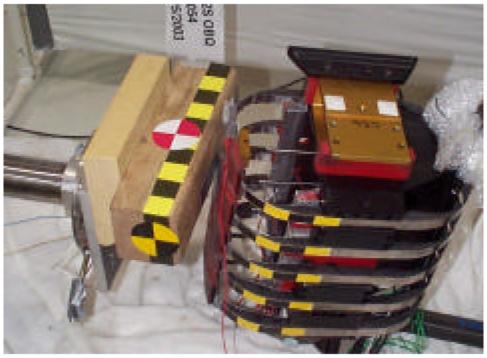


Figure 108. Original SID-IIs setup in 15º oblique, 10º upward configuration

In these tests, the centerline of rib 2 was aligned with the centerline of the simulated armrest impact head. Contact was made only with ribs 1, 2, and 3 (thoracic ribs) for all tests. The same rib sets were utilized on both the FRG and the Original SID-IIs to eliminate variability due to differences in rib response. The impact velocity was approximately 5 mph for all impacts. This velocity allowed for a fair amount of rib deflection, while maintaining an energy level below the threshold of instrumentation damage to the Original SID-IIs.

Neither the Original nor the FRG instrumentation was damaged during this series, but the Original dummy did sustain gouges in the rib damping material due to rib "jump" (Figure 109). "Rib jump" occurs when the ribs extend outside of the rib guides and are able to move out-of-plane in a vertical fashion. This action resulted in damaged ribs and/or bent potentiometers in sled tests (see Section 4). Figures 110 and 111 illustrate comparisons between the Original and FRG SID-IIs dummies in various impact modes from Dynamic Compression Test Series IV. "Rib jumping" is evident in the Original dummy, but is absent in the FRG in both oblique and upward test scenarios.

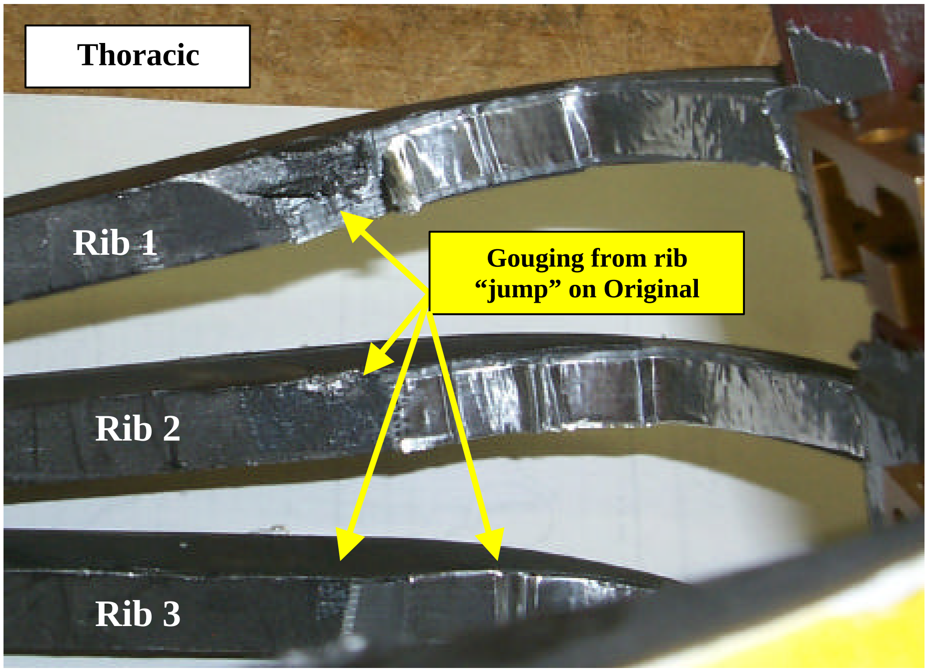


Figure 109. Gouging from rib jump on Original SID-IIs during Dynamic Compression Series IV

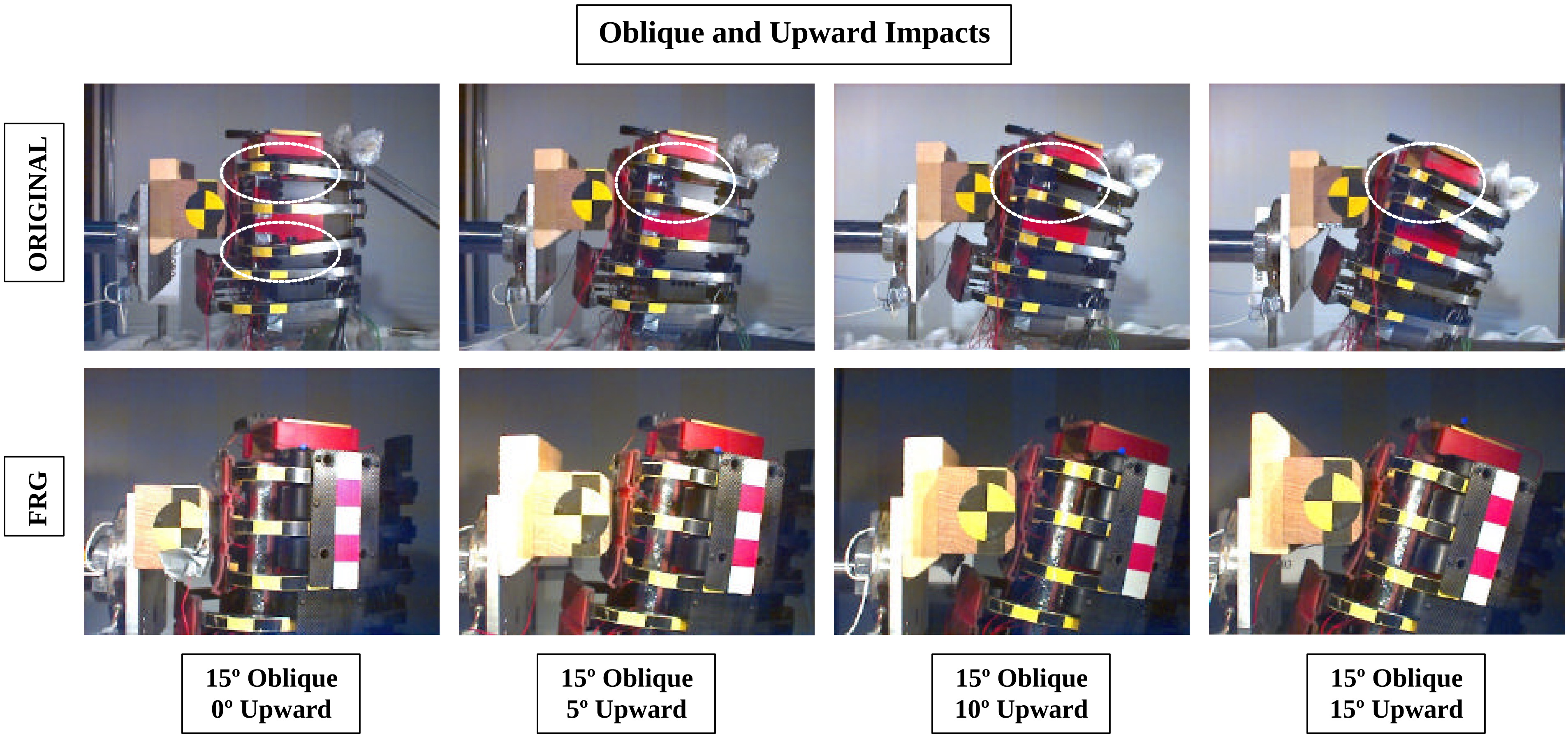


Figure 110. Comparison between the Original (top row) and FRG (bottom row) SID-IIs thorax responses for oblique, upward, impact configurations from Dynamic Compression Test Series IV (circled areas denote "rib jump")

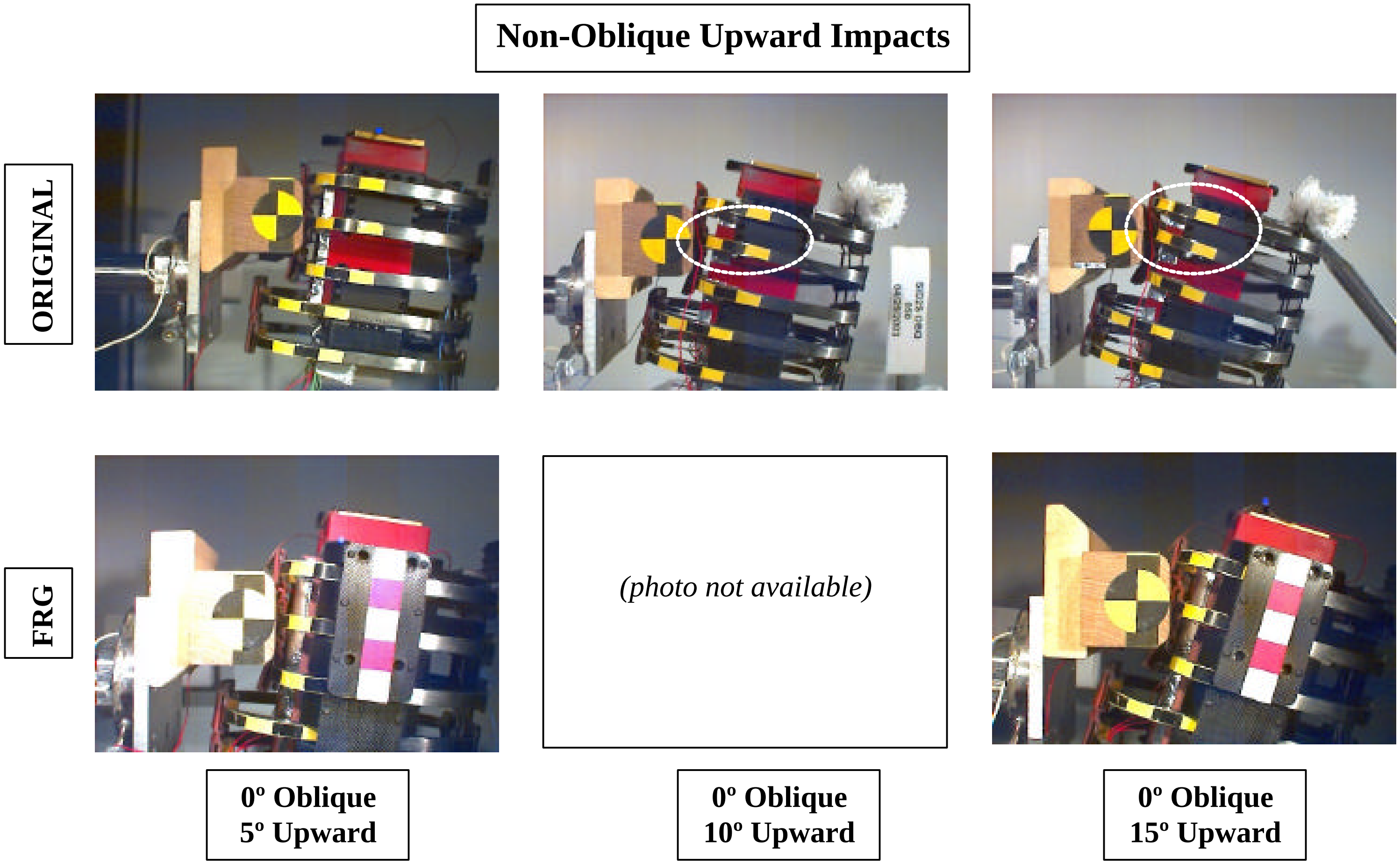


Figure 111. Comparison between the Original (top row) and FRG (bottom row) SID-IIs thorax responses for upward impact configurations from Dynamic Compression Test Series IV (circled areas denote "rib jump")

Table 29 presents the peak rib deflections for the comparison results of testing. Repeat test results demonstrate repeatable setup, using peak dummy rib deflections as a gage. In all cases, the FRG and Original SID-IIs deflections were comparable; differences between deflections for the two dummies did not exceed more than a few millimeters. Plots are shown in Figure 112 through 119. Differences in plot shapes between the two dummies are evident in the 15° oblique tests. This is due to contact of the ribs with the rigid rib stop in the FRG, while the Original SID-IIs has a more compliant rib stop.

Table 29. Comparison Between the FRG and Original SID-IIs in Upwards, Oblique Impacts at 5.0 mph (Series IV)

Dummy	Oblique Angle (deg)	Upwards Angle (deg)	Test # SID2sOBQ_	Rib1 Disp (mm)	Rib2 Disp (mm)	Rib3 Disp (mm)
Orig	0	0	42	45	54	47
FRG			59	45	52	47
			60	45	52	47
Orig		5	76	41	50	46
			77	41	49	44
FRG			64	42	50	47
			67	41	50	46
Orig		10	50	36	46	46
			51	36	46	46
FRG			65	36	48	48
			66	35	48	49
Orig		15	52	37	47	47
FRG			73	36	49	47
			74	37	50	48
Orig	15	0	57	32	38	33
			58	32	39	33
FRG			61	31	35	31
			62	30	34	32
Orig		5	56	28	36	35
FRG			63	30	32	31
			68	30	35	33
Orig		10	54	28	35	33
FRG			69	26	32	33
			70	26	32	34
Orig		15	53*	21*	31	33
FRG			71	27	32	31
			72	27	33	32

*Thorax fixture movement (approximately 6mm as indicated by ram displacement measurement) accounted for the lack of rib deflection

Note: Values in **RED** indicate rib stop contact

Non-Oblique (0°) | **Oblique (15°)**

0° Upwards

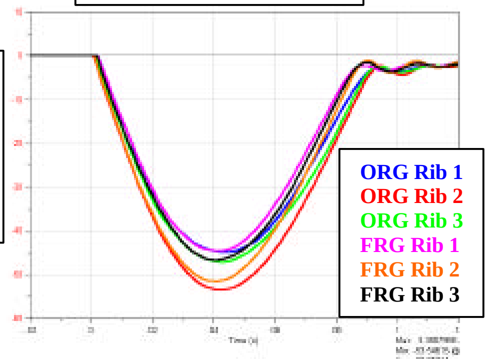


Figure 112. FRG (Test 59) and Original (Test 42) Comparison

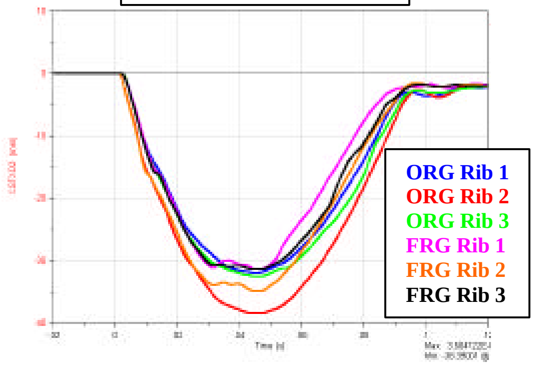


Figure 113. FRG (Test 61) and Original (Test 57) Comparison

5° Upwards

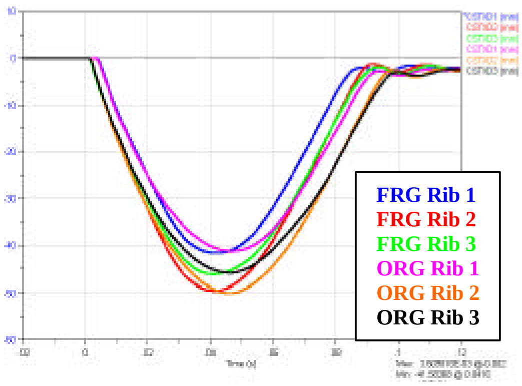


Figure 114. FRG (Test 67) and Original (Test76) Comparison

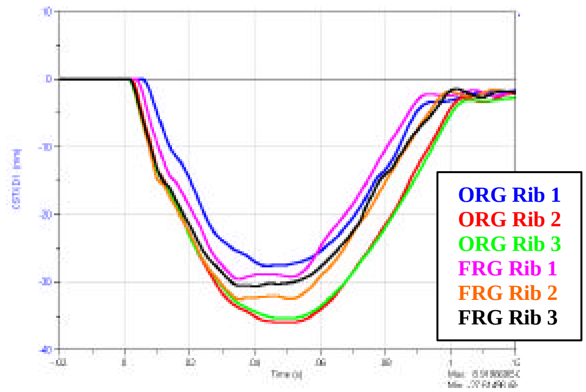


Figure 115. FRG (Test 63) and Original (Test 56) Comparison

10° Upwards

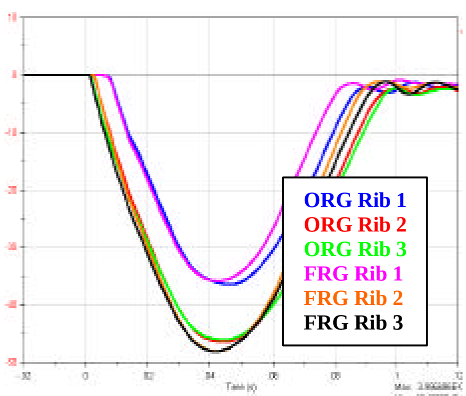


Figure 116. FRG (Test 65) and Original (Test 50) Comparison

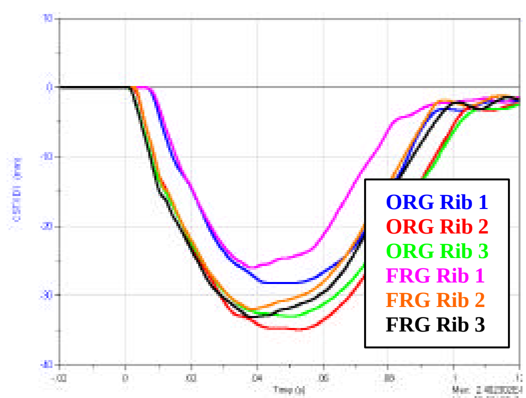


Figure 117. FRG (Test 69) and Original (Test 54) Comparison

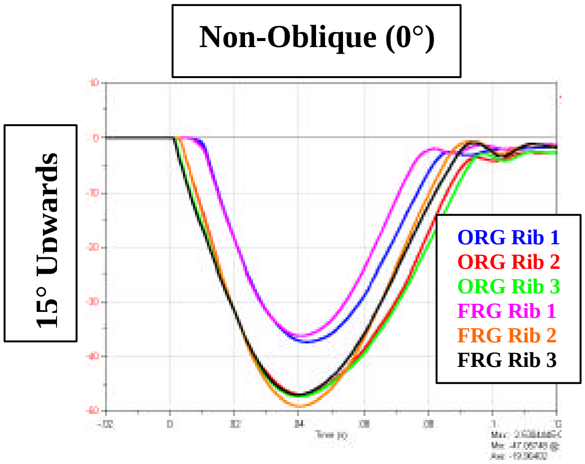


Figure 118. FRG (Test 73) and Original (Test 52) Comparison

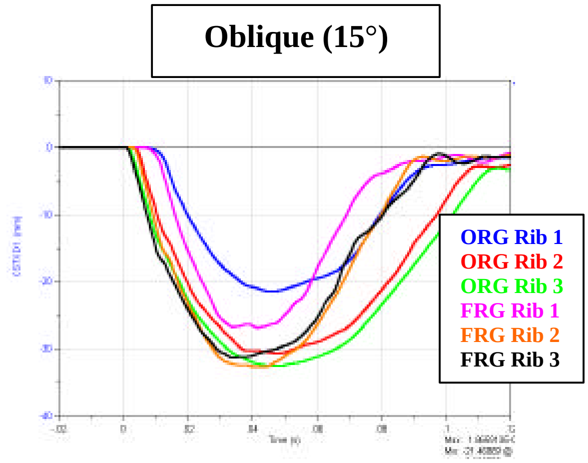


Figure 119. FRG (Test 71) and Original (Test 53) Comparison (Note: see Table 28 for Original Rib 1 explanation)

Figure 120 presents a summary of the results of this test series. When an upward or oblique component was applied to the Original SID-IIs, "rib jumping" was evident. The FRG in the same scenario contained the ribs within the rib guide plane. Both the Original and the FRG dummy rib deflections responded similarly in all impacts, even those including both oblique and upward components.

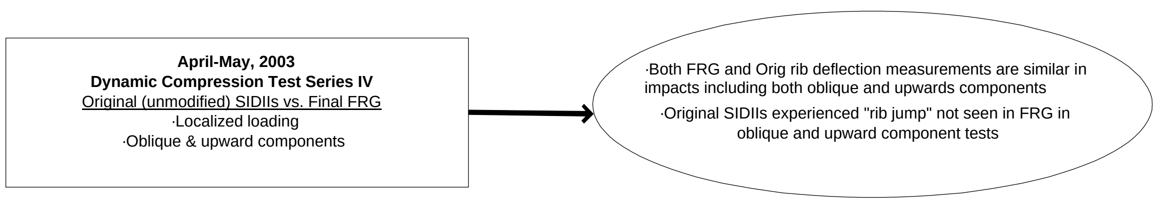


Figure 120. Summary of Dynamic Compression Test Series IV

7.9 Dynamic Compression Test Series V (June 2003)

In addition to the comparison tests conducted at 5mph, both the Original and FRG SID-IIs dummies were tested in a 0º oblique, 15º upward configuration (Figure 111) at an increased velocity of 6.4 mph. The setup was the same as Dynamic Compression Series IV, except for the change in velocity. Increasing the velocity allowed for additional potentiometer stroke and upward force on the ribs. These tests were conducted to compare the two dummies in this situation and examine their durability.

First, the Original dummy thorax was subjected to a localized impact centered on thoracic rib 2 (6.4 mph, 0º oblique, 15º upward). The dummy was then carefully inspected for damage to potentiometers and ribs. Table 30 shows the results of the tests conducted with both dummies at 6.4 mph and resulting damages in the Original SID-IIs, which were absent in the FRG. Two types of damages occurred: pot shafts bent, and the pot bushings pulled out of the potentiometer bearing assembly.

Table 30. Comparison Between the Original SID-IIs and FRG Dummies with an Upward Impact Component at Increased Velocity

Dummy	Configuration	Velocity (mph)	Test #	Rib1 Disp (mm)	Rib2 Disp (mm)	Rib3 Disp (mm)	Pot Shafts Bent?	Bushing Pulled Out of Bearing
Orig	0º Oblique and 15º Upward	6.4	88	47	60	61	No	Yes Pots1,2,3
			Pre-Test 89: new pot installed at rib 2; re-glued pots at ribs 1 & 3					
			89	48	61	60	Yes Pot 2	Yes Pots 1,2
			Pre-Test 90: new pot installed at rib 2; re-glue pot at rib 1					
			90	47	62	61	Yes Pots 1,2	Yes Pot 2
FRG			Pre-Test 91: new pots installed at ribs 1 and 2					
			91	46	58	53	No	No
			92	45	57	53	No	No

In Test 88, it was noted that the plastic bushings, which are glued into the metal bearing in the gimble assemblies (of both the FRG and Original dummies) were pulled outward from the metal bearing by the "prying" force associated with the large upward force component of this test. This occurred on all three thoracic rib potentiometers. Figure 121 shows a potentiometer with the bushing sleeve intact in the bearing; Figure 122 illustrates the case where the bushing has been pulled outward from the bearing as in Test 88. The occurrence is significant because when the sleeve is pulled outward from the bearing, the bearing allows more upward potentiometer shaft rotation (roughly about 10º more). This may explain why no potentiometer shaft bending occurred in this test, even with such a large upward force; the bushings (and pots) were free to rotate farther upward before hitting the top of the bearing and being forced into a bending mode.

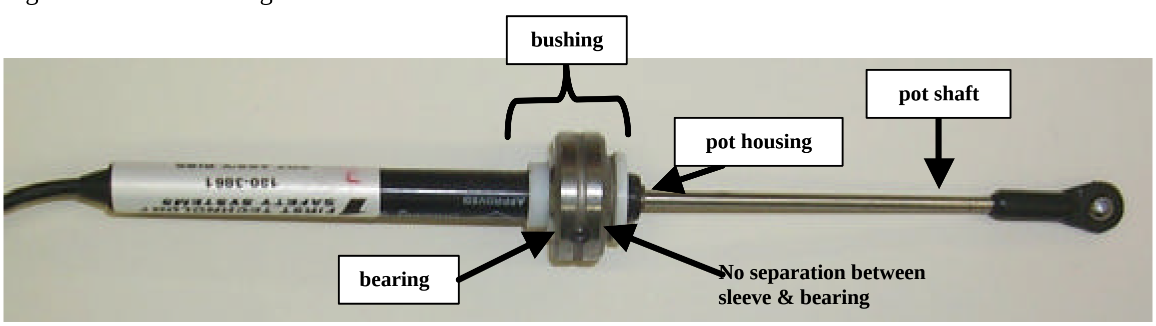


Figure 121. SID-IIs potentiometer assembly with bushing sleeve intact in metal bearing

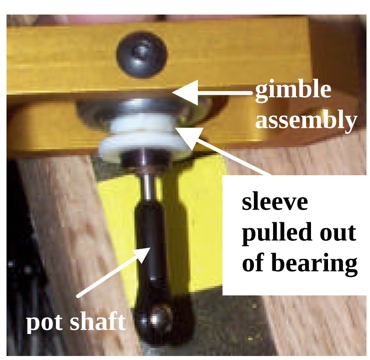


Figure 122. Bushing sleeve separation from metal bearing

For the next test (89), the bushings were either glued back into the bearings (pots 1 and 3) or replaced with a new, unused potentiometer assembly (pot 2). In this test, the Rib 2 potentiometer shaft bent upward from impact (Figure 123). In addition, the plastic bushings pulled outward from the bearings in both pots 1 and 2.

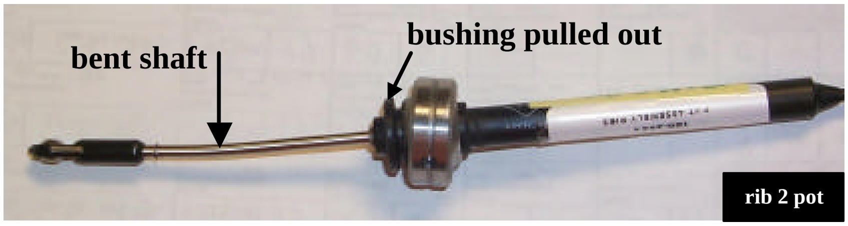


Figure 123. Damage to potentiometer shaft and bushing during Test 89

After Test 89, the bushing for potentiometer 1 was glued back into the bearing, pot 2 was replaced, and Test 90 was then conducted. In this test, the Rib 1 and Rib 2 potentiometer shafts were bent upward (Figure 124) and the bushing for pot 2 was pulled outward. Figure 125 shows the damage mode for the potentiometers; the ribs expanded outward beyond the rib guides, the ribs "jumped", and the upward force resulted in the potentiometer shaft bending about the bearing.

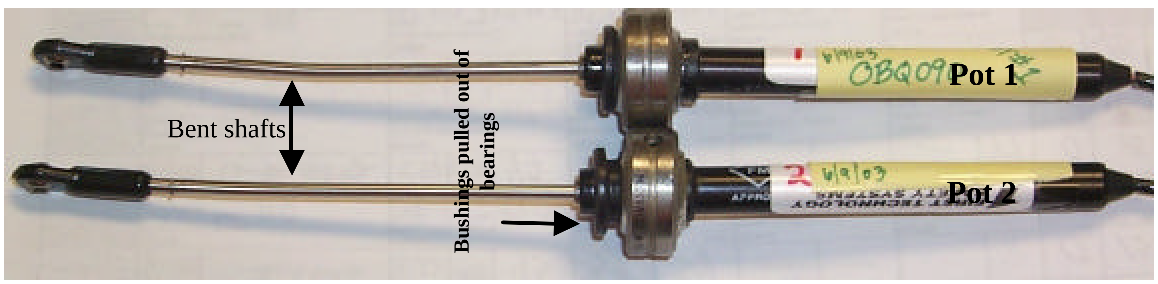


Figure 124. Potentiometers 1 and 2 showing pot bending damage and bushing pull-out after Test 90

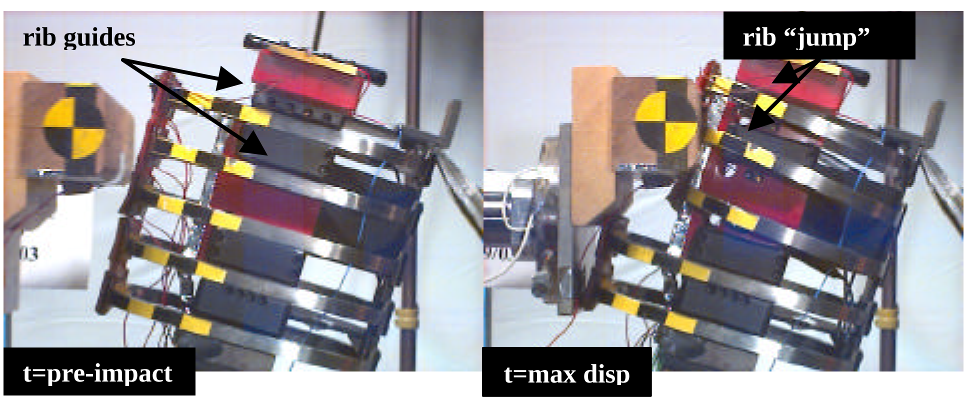


Figure 125. Vertical displacement ("jumping") of ribs beyond rib guides which led to potentiometer damage on the Original SID-IIs (Test 90)

In Tests 91 and 92, the FRG was subjected to the same input configuration to determine if rib or potentiometer damage would occur. No damage was evident in the FRG tests (Figure 126) to either the potentiometer shafts or the bushing inserts. Figure 127 illustrates "rib jumping" in the Original SID-IIs, which is absent in the FRG, at maximum compression (Tests 90 and 91 respectively).

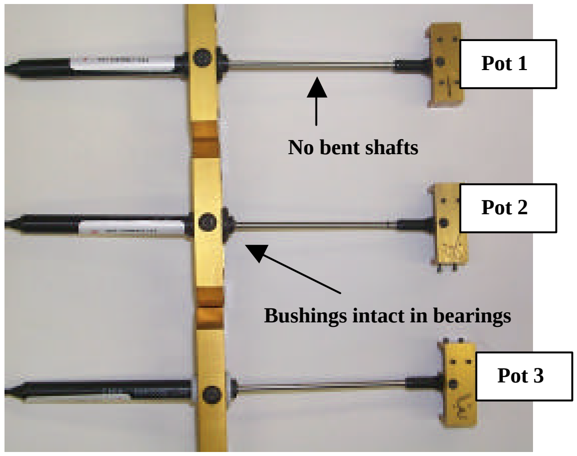


Figure 126. No damage to pots in FRG Tests 91 and 92

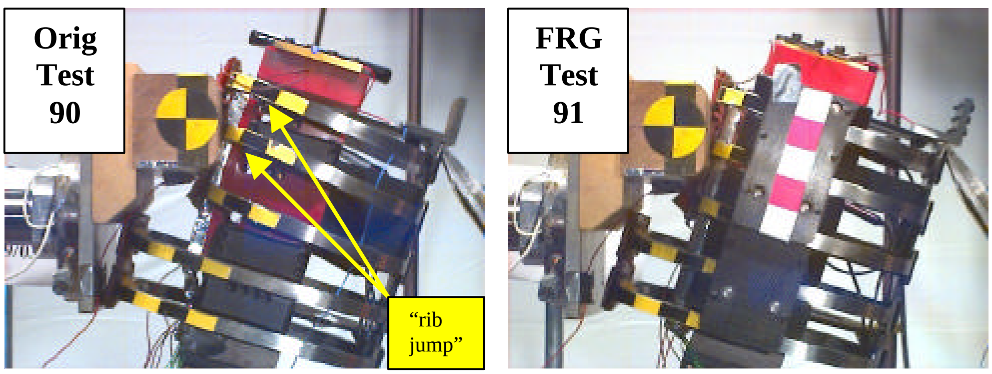


Figure 127. Comparison between Original and FRG SID-IIs in 0º oblique, 15º upward impact at 6.4 mph. Evidence of "rib jumping", which damaged pots in the Original dummy, is absent in the FRG.

Figure 128 presents a summary of the results of this test series. When an upward component (15°) was applied to the SID-IIs at an increased velocity, "rib jumping" was evident in the Original SID-IIs; this resulted in damages to the potentiometers including bent shafts and bushing sleeves being pulled out of the bearings in the potentiometer assembly. The FRG dummy, when tested in the same scenario, did not experience any damage to the potentiometers.

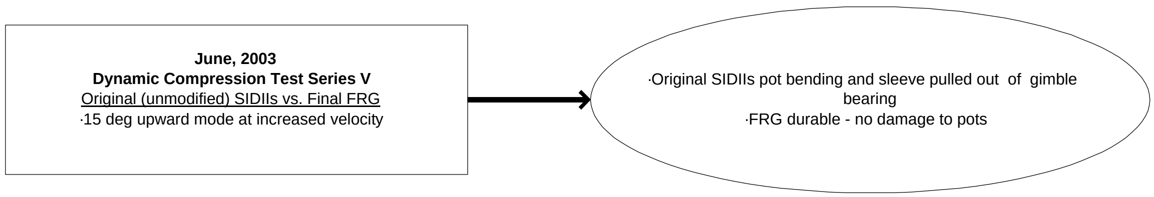


Figure 128. Summary of Dynamic Compression Series V

7.10 Conclusion of FTSS Prototype FRG Evaluation

In June 2002 VRTC received the FTSS Prototype FRG SID-IIs. In July 2002, VRTC performed Quasi-Static Compression, Dynamic Compression and Sled Series VI tests, which resulted in further design modifications to the SID-IIs. The FRG front and rear cover plates were split between the thorax and abdomen ribs to decouple the thorax and abdomen regions, allowing the regions to move independently of each other and preventing binding of the guides and pins. In addition, the FRG cover plates were changed from flexible urethane to stiff carbon fiber material to aid in the movement of the plates without binding and stiffer springs were implemented in the FRG system to optimize the speed of return of the plates to their initial positions. Finally, the abdomen pad height was reduced by ¼" to prevent interference with the thorax pad and ribs, and the thorax and abdomen pads were attached directly to the ribs with cable ties in order to improve repeatability in the thorax and abdomen regions. These modifications, along with the previous modifications that include more robust rib stops, a new shoulder rib and shoulder rib guide, make up the final FRG SID-IIs, as shown in Figures 61(a) and (b).

Sled Series VI showed the final FRG design to be effective at preventing damage seen previously in the thorax and abdomen of the Original SID-IIs. OOP Airbag II tests showed the new shoulder rib and rib guide to be effective at preventing damage to the shoulder region, which also previously damaged with the Original SID-IIs. Sled Series VII showed the FRG dummy responses to be comparable to the Original in ISO Neck and Shoulder Biofidelity and Padded Flat Wall Biofidelity tests, with the following exceptions, (1) in the ISO Neck and Shoulder tests only a slight increase in lateral shoulder force, and (2) in the High-speed Padded Flat wall tests the FRG deflections were 10% smaller, thorax load wall forces were 17% larger, and T1 accelerations were 20% larger than in the Original dummy.

Over 100 Dynamic Compression Tests were performed between January and June 2003 to compare the responses of the final FRG SID-IIs to those of the Original SID-IIs. Controlled, oblique impact tests were conducted in the laboratory at various angles of obliqueness in order to examine the responses of both designs. In pure lateral tests at 5.5 mph, the two dummies responded similarly. In pure lateral tests at 6.5 mph, the FRG dummy exhibited a stiffer deflection response (FRG peak deflections: 45-51mm; Original peak deflections: 51-56mm). Although further investigation is required to confirm the cause for the increase in stiffness, it is suspected that, as the ribs deflect and the springs of the FRG system compress, the stiffness of the dummy increases.

Small increases in obliqueness of impact angle result in significantly reduced rib deflection measurements due to "pot swing," which occurs in both the FRG and Original dummies. Eventually, when enough oblique angle is introduced, the ribs will contact the rib stops of both dummies, limiting deflection altogether. In repeated oblique impact test conditions, the FRG and Original dummies exhibited comparable deflections; however, maximum rib deflection measurements in oblique impacts were up to 50% less than those of pure lateral impacts for both dummies. Additionally, "coupler drag" is responsible for decreased deflections of adjacent, non-impacted ribs in pure lateral as well as oblique impacts.

In impacts with both oblique and upward components, both the FRG and Original dummy rib deflections responded similarly; however, the Original SID-IIs experienced “rib jump” whereas the FRG did not. In 15º upward comparison tests, the Original dummy sustained bent potentiometer shafts and pulled-out plastic sleeves from the gimble bearing, while the FRG remained intact. In all test conditions of the Dynamic Compression Tests, the FRG proved to be durable and repeatable.

8. Overall Conclusions

During the SID-IIs evaluation, a total of 232 tests were performed at VRTC with the Original SID-IIs and various versions of the redesigned FRG SID-IIs (Figure 129).

Test Type	FRG	Original	Total
Static Compression	10	2	12
Dynamic Compression	99	51	150
Sled tests	22	28	50
OOP Tests	2	18*	20
Total	133	99	232

* includes various tests from Crashworthiness Group

Figure 129. Number and types of tests conducted during the evaluation of the SID-IIs

The following conclusions were drawn from the evaluation of the SID-IIs dummy:

- In *both* the Original and FRG SID-IIs dummies
  - "Coupler drag" results in smaller deflection of ribs adjacent to impacted ribs
  - Similar rib deflections resulted in all component level test cases except one (6.6mph, pure lateral dynamic compression test resulting in 6mm less deflection in the FRG compared to the Original; further examination required)
  - Rotation about the z-axis (oblique impact) has the greatest influence on SID-IIs rib deflection magnitude
  - In oblique tests, small changes in impact angle result in large decreases in rib deflection measurement due to "pot swing" and/or rib contact with the spine box/rib stop
  - Maximum rib deflection measurements during oblique impacts were up to 50% less than those of pure lateral impacts
  - The current design of the measurement apparatus measures deflections in the line of action of the impacting force only during purely lateral impacts and is thus not adequate for measuring deflections in the line of action of oblique impacts

- "Rib jump"
  - Occurs in the Original, but *not* the FRG SID-IIs
  - Occurs when the ribs expand beyond the rib guides and are allowed to move vertically out-of-plane
  - Can damage ribs and instrumentation (rib potentiometers)

- The Original SID-IIs
  - Sustained bent pot shafts and damaged ribs (durability issues) in several sled and component tests due to "rib jump"
  - Experienced "rib jump" during certain test scenarios which included upward and/or oblique force components

- The FRG SID-IIs (including floating rib guides, new rib stops, improved shoulder guide, and redesigned shoulder rib)
  - Provides improved durability over the Original SID-IIs
  - Successfully eliminated "rib jump" in all tests
  - Improves reliability in lateral deflection measurements since ribs stay in horizontal plane
  - Increases stiffness at deflections larger than 45 mm
  - Displays similar biofidelity responses as that of the Original SID-IIs in LPF tests
  - Displays a slight increase in lateral shoulder force in the ISO Neck and Shoulder tests

- Exhibits 10% smaller deflections, 17% larger thorax load wall forces and 20% larger T1 accelerations than the Original dummy in the High-speed Padded Flat wall tests

9. References

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APPENDIX A

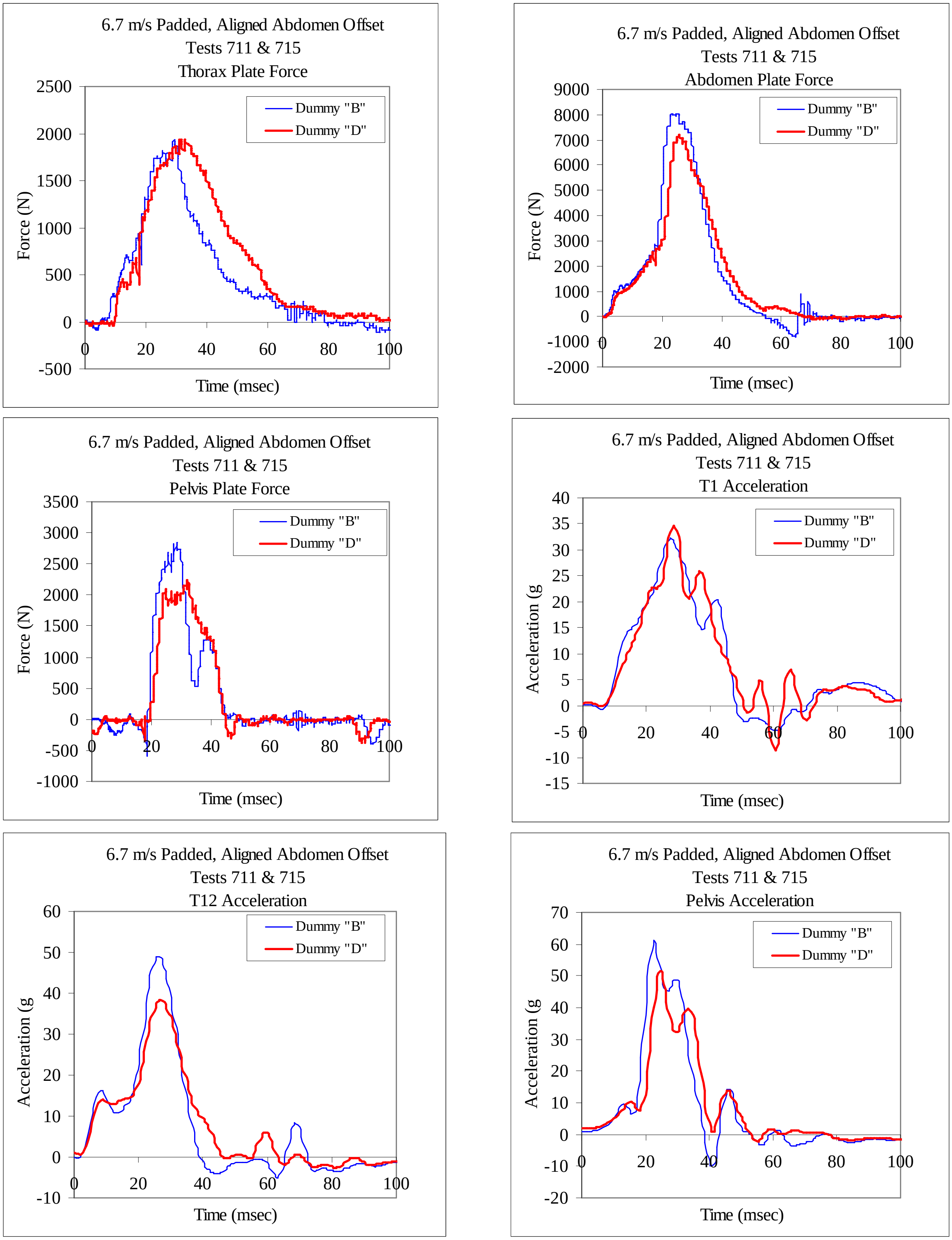

Figure A1. Comparison data traces from Aligned, Padded Abdomen Offset Tests 711 and 715 with dummies B and D, respectively.

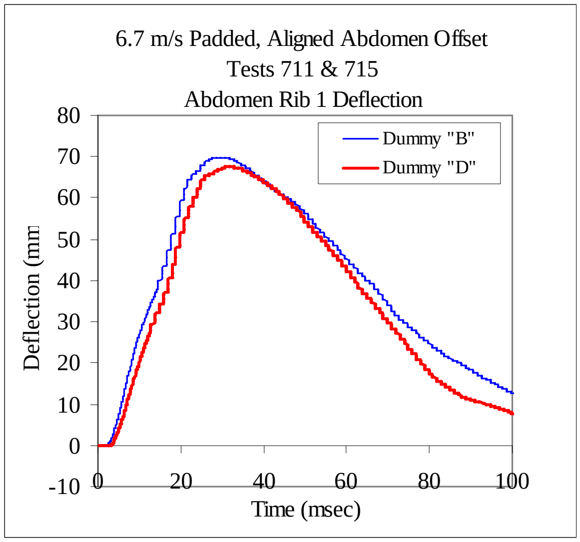

Figure A1. Continued.

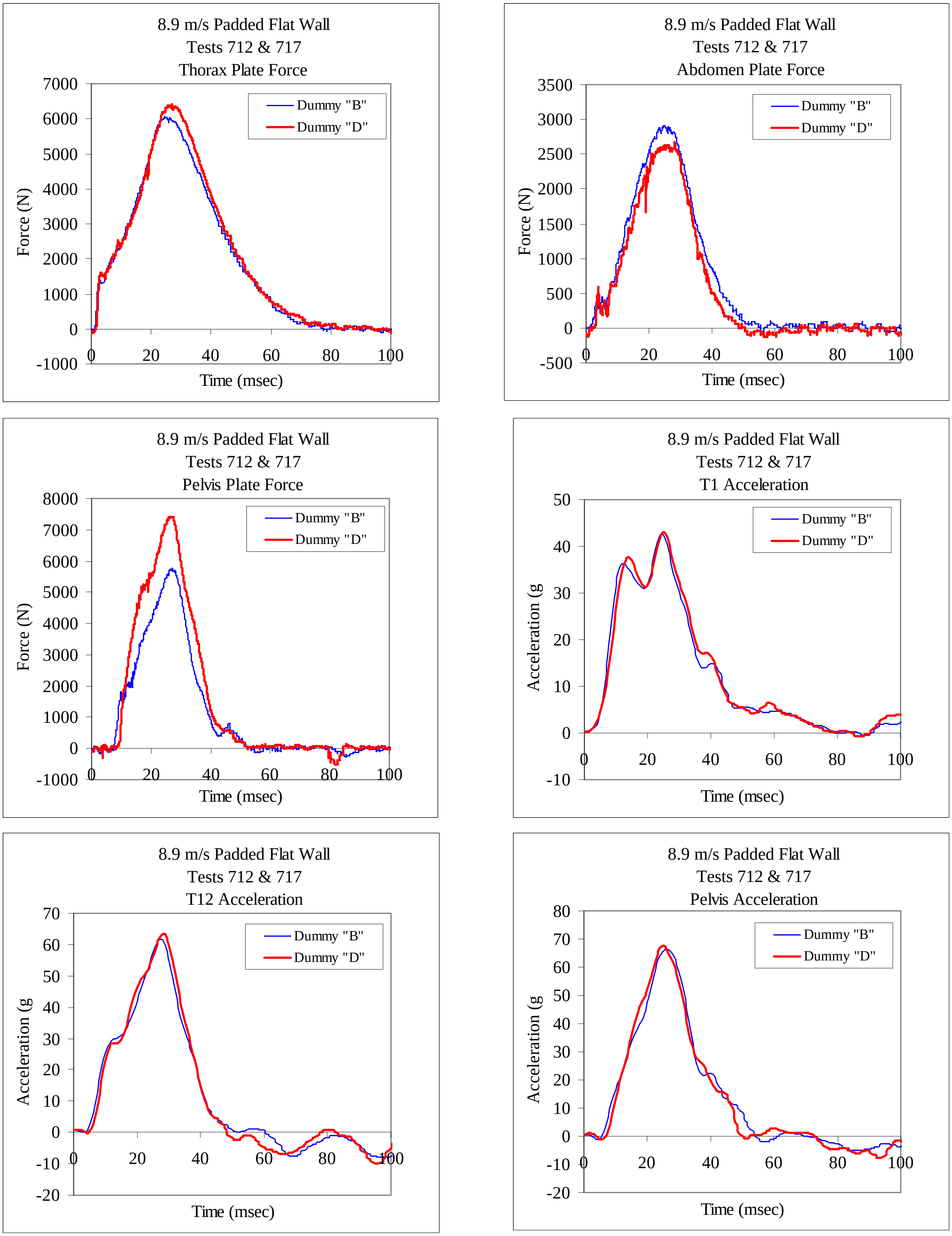

Figure A2. Comparison data traces from HPF Tests 712 and 717 with dummies B and D, respectively.

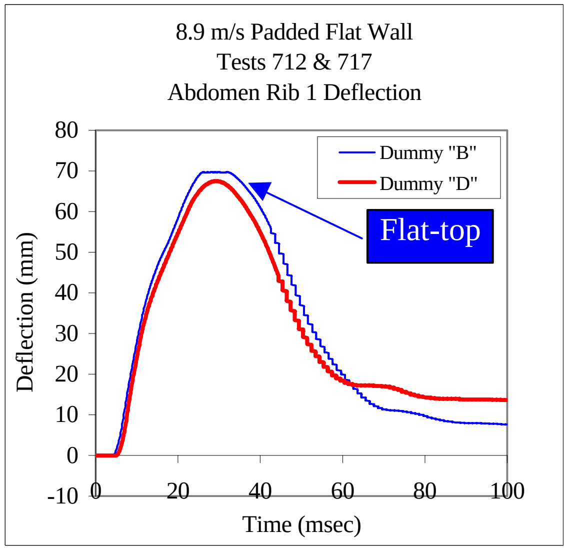

Figure A2. Continued.